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CARRYING CAPACITY IN REGIONAL ENVIRONMENTAL MANAGEMENT

UTAH STATE UNIVERSITY

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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This report examines the concept of carrying capacity in the context of regional environmental management. Historically, the notion of carrying capacity developed out of descriptions of the growth & dynamics of natural populations, and as such has been used as basis for range & forest management practices. Applied to human activities, however, the concept must be broadened to include the complex relations among resources, infrastructure and productive activities, residuals, and societal preferences for quality of life within both the natural & human environments. Four dimensions of a human oriented carrying capacity--resource/production, environment/residuals, infrastructure/congestion, & production/societal relations--are described within normative & operational definitions of carrying capacity. Carrying capacity is then viewed from the standpoint of resources, regional structure, & regional models to see how it fits within the theoretical & analytical considerations related to these areas. A carrying capacity-based planning process is described where the forces for change in the region are analyzed in terms of impacts on identified carrying capacity indices & compared with desired levels to pinpoint areas in which capacities have been exceeded. Consideration in applying carrying capacity concepts in local/urban planning are discussed.

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CARRYING CAPACITY IN REGIONAL ENVIRONMENTAL MANAGEMENT

by

A. B. Bishop, H. H. Fullerton, A. B. Crawford,
M. D. Chambers, and M. McKee

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This report examines the concept of carrying capacity in the context of regional environmental management. Historically, the notion of carrying capacity developed out of descriptions of the growth and dynamics of natural populations, and as such has been used as basis for range and forest management practices. Applied to human activities, however, the concept of carrying capacity must be broadened to include the complex relations among resources, infrastructure and productive activities, residuals, and societal preferences for quality of life within both the natural and human environments. Four dimensions of a human oriented carrying capacity--resource/production, environment/residuals, infrastructure/congestion, and production/societal relations--are described within normative and operational definitions of carrying capacity. Carrying capacity is then viewed from the standpoint of resources, regional structure, and regional models to see how it fits within the theoretical and analytical considerations related to these areas. A carrying capacity-based planning process is described where the forces for change in the region are analyzed in terms of impacts on identified carrying capacity indices and compared with desired levels to pinpoint areas in which capacities have been exceeded. The process contains an overview of how models can be linked and integrated in order to provide information on carrying capacities and trade offs. Consideration in applying carrying capacity concepts in local/urban planning are discussed, including identification of regional driving forces, resource analysis, capacity impacts of future change, and formulation and analysis of management strategies.

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SECTION I

CONCLUSIONS

The general conclusion of the study is that the concept of carrying capacity has appropriate application in regional planning setting. However, the concept must be broadened to include the interaction of human and natural environments.

As a basis for regional environmental management, carrying capacity should not be interpreted as referring simply to the number of people that a given resource base is capable of supporting under certain specified conditions. Rather, regional carrying capacity must have reference to the interrelated capacities of (1) resources to support productive processes, (2) processes to supply essential goods and services, and to provide acceptable quality-of-life levels, (3) infrastructure resources to distribute materials and goods and services efficiently, and (4) environmental media to assimilate the wastes generated from productive and consumptive activities and remain within acceptable quality levels.

As a planning concept, carrying capacity has a normative dimension, reflected by the requirement that the outputs of production--goods and services, on the one hand, and wastes and residuals, on the other--conform to established standards or norms; and a descriptive dimension, reflected by the requirement that carrying capacity conditions be measured and related to these norms.

As a basis for regional environmental management, carrying capacity should be viewed in the context of a planning process oriented toward the task of formulating policies and programs for managing areas of induced change and development.

As an objective for regional modeling, the use of carrying capacity as a framework for utilizing a range of multiple modeling and analytical techniques will lead to more fruitful results than attempting to develop a single carrying capacity model. This conclusion is prompted in part by the need to provide analysis at various scales of spatial and temporal resolution.

A general carrying capacity-based planning process is formulated to develop and support these conclusions.

SECTION II

RECOMMENDATIONS

The following recommendations generally apply to the use of the carrying capacity concept in regional environmental management and to its further development as a regional planning tool.

> For application in a regional setting carrying capacity should be a multidimensional concept oriented to both the human and natural environment and not a narrow single-number concept of population carrying capacity.
>
> Regional carrying capacity analyses should be used within an alternative futures planning mode as a means of examining the impact of exogenous forces on a region.
>
> Carrying capacity analyses should draw upon and appropriately modify and/or synthesize disciplinary models that are already operational and tested, rather than rely on the development of a single carrying capacity model.
>
> Indexing techniques which convey carrying capacity information to decision and policy makers need to be developed.

Additional research should be undertaken to formulate carrying capacity limits or ranges, and the feasibility of basing these limits or ranges on resilience measurements should be studied.

The carrying capacity-based planning process described herein should be applied and tested in an actual planning context.

SECTION III

CARRYING CAPACITY: A PERSPECTIVE FOR ENVIRONMENTAL MANAGEMENT

GROWTH AND CARRYING CAPACITY-- INTRODUCTION AND OVERVIEW

Carrying Capacity: Interaction of Natural and Human Environments

The capacity of natural and human environments to accommodate or absorb change without experiencing conditions of instability and attendant degradation is a significant concern in view of current trends of urban growth and development. Indeed, it appears that the ability of the environment to sustain particular levels of activity may already have been exceeded in some areas, and in others resource management options are rapidly being foreclosed.

Recognizing that the quantity, productivity, and regenerative capacity of a region's resources are limited, a strong motivation exists for a conceptualization of environmental carrying capacity as a basis for regional planning and evaluation. Scarce resources must be managed in the context of many competing demands, and the natural and human environments must withstand perturbations caused by changes in man's social and economic activities.

The Human Environment--

Viewing the term human environment broadly as man's surroundings created through his manipulation and use of resources, it can be fairly said that the basic goals that have been sought in structuring the human environment are growth oriented. Individual expectations and institutional structures assume and often require growth (Cooper and Vlasin, no date). Growth, as reflected by increasing flow rates of materials and energies, places ever increasing demand on the production and assimilation capabilities of resources in the natural environment. Examples of ecological problems stemming from resource demands are reflected in both the urban and rural systems (Bahr et al., 1972).

Man has achieved very high productivity in rural-agricultural systems. However, the efficiency of production is a result of a tremendous energy cost required in order to stabilize the system. Two expensive ways in which man asserts his own idea of stability are through irrigation to stabilize effects of periodic drought and application of pesticides to stabilize pest outbreaks; each is only partially successful. Other energy and environmental costs include not only direct costs such as mining and supplying nutrients to the soil, fabricating farm machinery, but also indirect or unanticipated costs such as depletion of groundwater resources at a greater rate than they are being replenished or accelerating the flow of nutrients through crops with potential costs to future generations from eutrophication of water bodies.

The urban-industrial system can act to either accelerate or inhibit energy flow through the ecosystem. Wherever urbanization has contributed limiting nutrients to the ecosystem, productivities may be stimulated. On the other hand, toxic by-products of industrialization (heavy metals, various organic compounds, acids, radioisotopes, etc.) usually inhibit productivities and limit diversity in natural systems. Urbanization also tends to concentrate wastes in relatively restricted parts of the ecosystem. Over time, these wastes are eventually dispersed throughout the ecosystem and ecosphere. However, immediate concentrations are often dangerous, and such localized concentrations give warning of what might happen to all resources in the future if present rates of waste disposal are continued.

The Natural Environment--

The natural environment represents a constraint on the human sector as a function of the rates at which it can produce raw material and assimilate residuals and wastes. The rates and capacities of the natural environment are fixed by evolutionary processes and are fitted to past environmental situations, not to future demands.

A certain rigidity of the natural environment is implied by the term "constraint." The natural environment has the capability of producing a certain output flow of products and assimilating a certain input flow of waste products. These processes can take place without disruption of the integrity of the natural community provided that boundary conditions are not exceeded. The magnitude of these transformation capabilities depends on the environmental conditions and the stage of ecosystem development or succession (Cooper and Vlasin).

Likewise, elasticity is as much a property of natural environments as are constraints or limits. Here the question is that of how much an ecosystem can be manipulated without "major" change. Stresses imposed on parts of an ecosystem, as with physical systems, are shared with other parts of the system. Many stress-relieving cycles are built into the ecosystem, which like other systems, appear to follow Le Chatelier's principle; i.e. systems will tend to compensate for stress.

Constraints define the stress limits within which the system will still return to its original condition. Whether man can relax these constraints in an ecosystem by ecological engineering or not is still an open question (Cooper and Vlasin). A basic problem is in recognizing and quantifying the magnitude of the ecological resource and identifying what proportion of the potential is committed to the base line demands imposed within the natural environment itself. The level of augmentation in structuring the human environment will thus be interdependent with the existing demands of the natural environment. Recognizing these capacities, the human sector must either be uncoupled from the natural environment (which is not feasible at present) or it must be reoriented to operate within the constraints of the "natural" sector or else further evolution of the natural system is forced.

Growth and Carrying Capacity

Virtually every urban center as well as natural ecosystems, is faced with problems of accommodating some degree of future growth and development. The evolution of our current demographic structure in the United States is the result of a variety of powerful economic and resource factors (Bahr et al., 1972). Factors influencing development were ready supplies of raw materials, water and cheap power, and cheap transportation (e.g., coastal areas, large rivers, or the Great Lakes).

Cooper and Vlasin note that the differences in spatial distribution of activities between natural and human environments are "the result of systematic responses to two selection processes (evolutionary versus economic) that are both rewarding efficiency but under different time domains and resource constraints. This difference lies at the heart of the conflict between economic growth and development versus environmental quality and stability."

Relation of Economic and Ecologic Systems--
Economists have aptly described the problems arising out of conflict in the progression of natural and human systems. The manifestations of this conflict appear in widely varying aspects that have been labeled "pollution." The problem of pollution arises out of two related aspects of economic activity, congestion and residuals.

Congestion is a problem that environmental and human resources have in common. Bower (1971) describes this for ecological systems as follows:

> In a low-density or economically undeveloped setting, an additional user of the natural environment may well impose essentially no cost on other users. As the density of development and the level of output increase, in the face of finite environmental resources, each additional user will impose additional costs associated with congestion on other

> users. This condition is termed an "externality" by economists--that is, the additional user does not take into account the costs he imposed on others in his decision to use a common property resource. Because there are no prices on the services rendered by the environmental media and since they cannot be exchanged between buyers and sellers in a market context, the price mechanism in a market economy is not effective in limiting the use of environmental resources.

The failure to consider the finite assimilative capacity of the environment leads to excessive use or congestion of the natural systems. Obvious parallels are present in the human environment particularly with public infrastructure resources such as freeway congestion at peak hours.

Disposition of residuals, or wastes from production and consumption activities, follows directly as the second major aspect of the pollution problem in environmental management. Figure 1 depicts this in graphical form. Production activities generate residuals and wastes which are discharged to the environmental resource base, and likewise

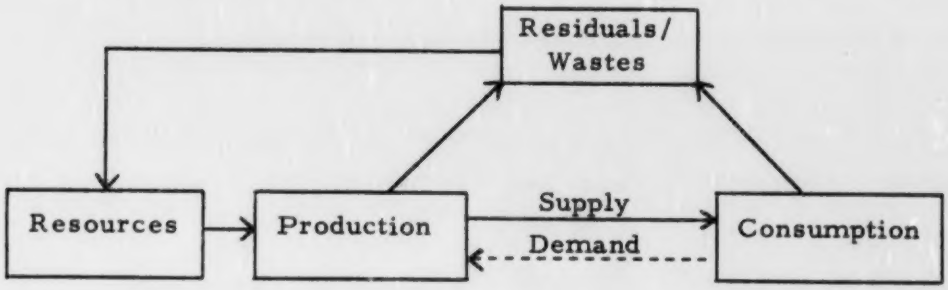


Figure 1. Schematic diagram of residuals generation.

consumption goods themselves produce or become residuals and are imposed on common pool resources as externalities. As Bower (1971) puts it: "All production and consumption activities utilize the assimilative capacity of the land, air, and water environments. While the services render by these environments are essential inputs into these activities, traditionally, no prices have been placed on these factor inputs. Hence, far more of them have been used than would be the case if the damages stemming from their use were properly taken into account through pricing." Extending this point, prohibiting the discharge of all residuals into the environment is in effect assigning an infinite value of pristine environmental quality. This would make the production of goods and services impossible since no production process is totally efficient, i.e. all production and consumption produces some residuals.

The following example also serves to point out that pollution is socially determined as well (Cooper and Vlasin):

> If one wants a trout stream and observes a trout stream, the stream is not polluted. If one wants a carp stream and gets a carp stream, the stream is not polluted. However, if one wants a trout stream and is forced to accept a carp stream then the environment is degraded and the stream is considered polluted. Biologically, a carp stream can be managed as a viable biological system, if that is the desired goal.
>
> The basic problem stems from the lack of any mechanism to enable a local region to converge on a single set of tradeoffs between resource utilization and environmental quality.

Carrying Capacity: Economic and Environmental Synthesis--

While economic constraints and efficiency have been the key determinants of regional growth in the past, these considerations now must be balanced by consideration of natural systems. Environmental constraints imposed by the ecological characteristics of any given region should be equally influential in determining the density and distribution of population, industry, agriculture, transportation and utility services, and the location of housing.

Using the description of Koenig and Tummala (1972):

> Each component of the natural environment--viz., lake, stream, airshed, terrestrial region, etc.--is considered to have a limited capacity for processing restricted classes of man-made materials and energy, depending upon the "quality" of the environmental component to be maintained. From an engineering design perspective, these limited capacities represent ecological constraints against which the technological and spatial features of man-made processes in agriculture and industry and human habitats must be designed. From an economic point of view they represent potential constraints on regional economic developments; and from an ecological point of view the mass-energy features of the production-consumption processes of the economy must be in dynamic equilibrium with a heterogeneous pattern of biological communities as a closed ecosystem.

Thus in managing the environment for quality regional growth, questions related to carrying capacity of environmental resources lie at the heart of the problem of finding socially acceptable systems which are also economically viable. These involve decisions related to types of raw materials for use in production processes, acceptable types of product outputs, pricing policies relating to residuals discharges, spatial location of economic activities, desired levels of environmental quality, methods for handling residuals (such as requiring specific levels of "waste treatment" rather than specifying a permitted quantity of discharge or establishing an effluent charge on each unit of residual discharge), and the time and spatial variations of assimilative capacity of various environmental media.

In approaching these questions, Bower (1971) indicates that "decisions and choices within the environmental sector are linked to decisions and choices in other sectors of the economy. Just as there are limited environmental resources, so there are limited human and capital resources." Carrying capacity as an environmental planning and management tool must explicitly recognize this allocation problem and seek to articulate the multiple trade offs among societal values involved. Boulding (1973) puts these ecologic-economic carrying capacities in perspective with the following comment:

> Today, ecology rather than economics seems to be taking on the role of the dismal science. All the dismal theorems, however, merely amount to saying that there are limitations. If these limitations are recognized and accepted, and organized action is directed towards them, there is no reason why they should be fatal. If we have, in fact, exceeded the human carrying capacity of the earth (and it is by no means clear that this is so), we will certainly have a rough time getting back to that capacity. There seems to be no inherent reason, however, why, once it has been achieved, a "spaceship earth" should not be both stable and reasonably agreeable.

ECOLOGICAL SYSTEMS AND CARRYING CAPACITY

The idea of carrying capacity was developed historically in connection with the study and description of the growth and dynamics of natural populations. Because of its historical origin, the term carrying capacity is generally thought of as population carrying capacity, a single number which is the population limit on a species in a given ecosystem or habitat.

The well known Malthusian equation describing population growth

$$\frac{dN}{dt} = kN$$

leads to the description of population growth as an exponential equation

$$N = N_o e^{kt}$$

in which N is population size, N_o is the initial population, and k is the growth rate per time period, t. The exponential growth model, of course, approaches no upper bound or population limit.

Population Carrying Capacity

The earliest equation for population growth that recognized limits of growth due to "carrying capacity" of the environment was proposed by Verhulst in the 18th century (Deitchman, 1972). The equation

$$\frac{dN}{dt} = (k \text{ [illegible] } \lambda N)N$$

leads to the logistics growth curve

$$N = \frac{k}{(\lambda - ce^{-kt})}$$

in which N is population size, k is population growth rate, λ is a density dependent population coefficient, and c is a constant of integration. The solution approaches the asymptote $N = k/\lambda$ after an initial exponential increase. The model does describe a number of biological and economic phenomena but it is highly sensitive to the values of the constants used.

The carrying capacity concept first received significant formal treatment in the form of a set of logistic growth equations developed by Lotka (1925) and Volterra (1926). The Lotka-Volterra equations are a set of coupled differential equations of the form:

$$\frac{dN_i}{dt} = \frac{r_i N_i}{K_i} \left[K_i - N_i - \sum_{j=1}^{m} \alpha_j N_j N_i \right]$$

in which r_i is the growth rate of the i^{th} population, N_i is the size of the i^{th} population, K_i is an upper limit on, or the carrying capacity of the i^{th} population, and α_j is a coefficient which represents the effect of such things as predation, competition, etc., of the j^{th} population on the i^{th} population. The Lotka-Volterra equations were originally purported to describe the change in the size of natural populations which (1) are in contact with one another, and (2) have an upper bound or limit on population density. This upper bound on population density was called the population carrying capacity (K), and was thought to be the result of density dependent negative feedback resulting from such things as resource shortages, disease, predation, etc., triggered by high population density.

The idea of a limit or upper bound on population density has been used for some time as a conceptual tool in the management of natural communities. Given a particular population living in a particular habitat, the carrying capacity or upper bound on population density for that population has generally been defined as the maximum population density which can be supported by the habitat without irreparable degradation of the habitat.

As populations are managed over time, and as the size of the managed population approaches the carrying capacity of the habitat, any one of three events might occur, as illustrated in Figure 2: (1) Management practices and natural controls on the quantity and quality of resources might limit the population near the carrying capacity; (2) management practices aimed at the removal of some population constraints might allow the population to exceed the carrying capacity, thus causing a degradation of the resource base and a long-run population decline to levels compatible with new quality levels of the resource; or (3) improvements in technology or management practices might change the habitat sufficiently to increase the carrying capacity for the population and thus allow the population to expand without environmental degradation.

The sustained yield concept is related to the notion of carrying capacity. From the standpoint of the management of biological communities, carrying capacity describes the biological or physical relationship between a given resource stock and its maximum sustained yield. Specifically, it is interpreted as the maximum number of individuals of a species that could be supported by a given habitat under various conditions of stress. The general goal implied is to maximize the productivity of the system, e.g., to maximize the number of cattle marketed from a given range, or to maximize the number of board feet of lumber harvested from a given forest, or to maximize the number of user-days of recreation at a particular site, subject to the constraint of nonimpairment or nondegradation of the supporting environmental system.

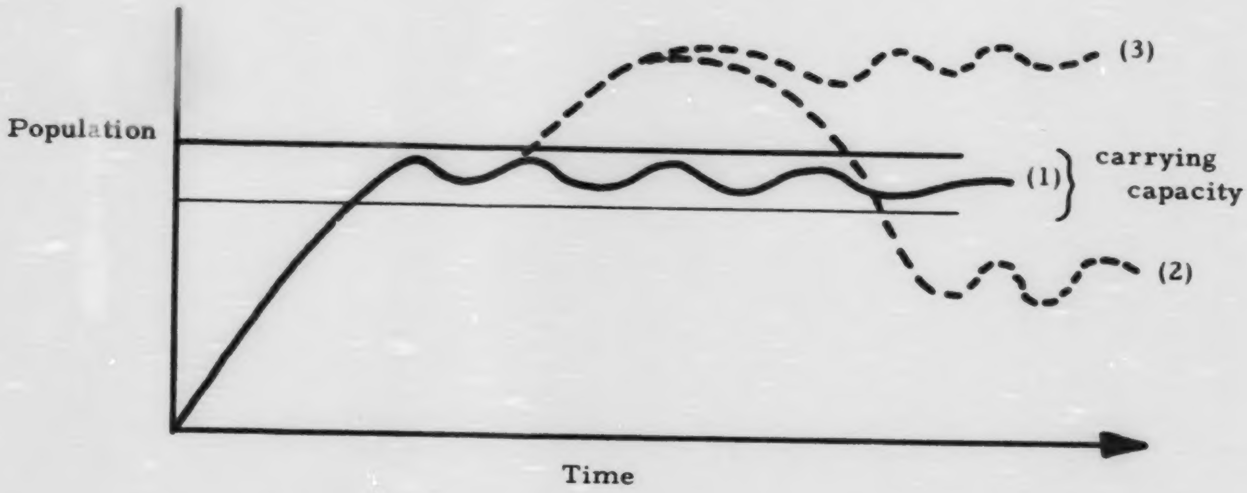


Figure 2. Population carrying capacity.

Focusing on the nonimpairment or nondegradation aspect of carrying capacity, Deitchman (1972) postulates an interaction model, following the general concept of the Volterra model, which involves four classes of "things" that enter into the pollution control problem. The four categories are resources, R_i (including pollution sinks); manufactured goods, M_i (interpreted broadly); populations, N_i, associated with these goods through production or associated services; and resulting wastes, W_i. The proposed set of equations takes the form:

$$\frac{dR_i}{dt} = k_{R_i} R_i + \beta_{R_i}^{-1} \sum_{j=1}^{n} a_{R_{ij}} R_i R_j + \gamma_{R_i}^{-1} \sum_{j=1}^{n} b_{R_{ij}} R_i M_j + \delta_{R_i}^{-1} \sum_{j=1}^{n} c_{R_{ij}} R_i N_j + \zeta_{R_i}^{-1} \sum_{j=1}^{n} d_{R_{ij}} R_i W_j$$

$$\frac{dM_i}{dt} = k_{M_i} M_i + \beta_{M_i}^{-1} \sum_{j=1}^{n} a_{M_{ij}} M_i R_j + \gamma_{M_i}^{-1} \sum_{j=1}^{n} b_{M_{ij}} M_i M_j + \delta_{M_i}^{-1} \sum_{j=1}^{n} c_{M_{ij}} M_i N_j + \zeta_{M_i}^{-1} \sum_{j=1}^{n} d_{M_{ij}} M_i W_j$$

$$\frac{dN_i}{dt} = k_{N_i} N_i + \beta_{N_i}^{-1} \sum_{j=1}^{n} a_{N_{ij}} N_i R_j + \gamma_{N_i}^{-1} \sum_{j=1}^{n} b_{N_{ij}} N_i M_j + \delta_{N_i}^{-1} \sum_{j=1}^{n} c_{N_{ij}} N_i N_j + \zeta_{N_i}^{-1} \sum_{j=1}^{n} d_{N_{ij}} N_i W_j$$

$$\frac{dW_i}{dt} = k_{W_i} W_i + \beta_{W_i}^{-1} \sum_{j=1}^{n} a_{W_{ij}} W_i R_j + \gamma_{W_i}^{-1} \sum_{j=1}^{n} b_{W_{ij}} W_i M_j + \delta_{W_i}^{-1} \sum_{j=1}^{n} c_{W_{ij}} W_i N_j + \zeta_{W_i}^{-1} \sum_{j=1}^{n} d_{W_{ij}} W_i W_j$$

Deitchman (1972) notes that in representing the pollution control system in open-loop form it is not necessary to assume rules of behavior about society or the economy. However, he states, "solution of these non-linear equations in closed mathematical form would, of course, be difficult; and for numerical solutions the coefficients must be quantified based on actual or projected data about the elements of the pollution control problem." However, Deitchman suggests the equations might be simplified and, from theoretical explorations (similar to those described by Goel, Maitra, and Montroll, 1971) and parametric numerical analysis, be used to explore stability and other characteristics of the system.

Ecosystem Properties and Carrying Capacity

If the concept of carrying capacity is to be useful it must enable the environmental manager to assess and evaluate the impacts of various proposals on regional environmental quality. To do this requires insight and understanding of the behavior and interaction of ecological and urban systems and of the ways in which the "health" of regional support systems can be measured and the time-dependent changes therein monitored. Whereas carrying capacity has primarily been framed in terms of the ecosystem, operationalizing it as a basis for environmental management will require finding corresponding processes that will be applicable to the human environment.

The search for parallel bases for studying urban and ecological systems is evidenced by the rising interest in "urban ecology." Holling and Orlans (1971) note that urban and ecological systems share four common characteristics:

1. A historical property since both respond to present and past events.
2. A spatial property, since they respond to events at several different points in space.
3. A systems property, since both encompass many different component activities with complex feedbacks and interactions.
4. A structural property, since they both exhibit characteristics of lags, thresholds and limits.

The second, and third, and particularly the fourth property, all intimate the potential usefulness of carrying capacity in the urban setting, and Holling and Goldberg (1971) indicate that a combination of these four characteristics produces distinctive system behaviors in terms of two properties, stability and resilience.

In describing stability, the example of temperature regulation of warm blooded animals used by Hardin (1963) and Holling and Goldberg (1971):

> In man the temperature is close to 98.6°F. If through sickness or through dramatic change in external temperature, the body temperature begins to rise or fall, then negative feedback processes bring the temperature back to the equilibrium level. But we note this regulation occurs only within limits. If the body temperature is forced too high--above 106°F., the excessive heat input defeats the regulation. The higher temperature increases metabolism which produces more heat, which produces higher temperature, and so on. The result is death.

Thus, stability in ecological and urban systems recognizes the existence of damping forces that tend to move the system towards an equilibrium state. However, given the dynamic nature of ecological and human systems, this equilibrium is likely to change continuously with time, and hence the importance of stability may be more in reference to the structure of the system itself. Also, as was seen in the temperature example, stability is not identified with just a single equilibrium point, but with the range within which the temperature can be regulated. This fact gives rise to a second important property of the ecosystem.

The concept of resilience is associated with the limits or domain of stability of the system. The representation in Figure 3 from Holling and Goldberg (1971) provides a graphical picture of resilience and its relation to stability. Holling (1969) and Holling and Goldberg (1971) have offered resilience as a potential measure of the integrity of complex systems. A generalized definition of resilience might be stated as follows:

> Given an n-dimensional state space analysis of a system, the system is said to be stable within a domain contained in that state space if it always tends toward an equilibrium point or an equilibrium oscillation within that domain. Resilience is a measure of the size of the domain of stability, the forces acting on the system within that domain, and the location of the system with respect to the boundary of the domain.

Transient shifts may force the system outside the domain of stability and cause radical changes to occur. The types of transients or forces have been classified in terms of pollution processes by Koenig and Tummala (1972). Using their illustration in Figure 4, they describe these as:

1. Nonpollution Levels: If the exchange rates are such that the ecological state will remain within a given quality region S_q^1, for example, they are said to be of a nonpolluting level. The

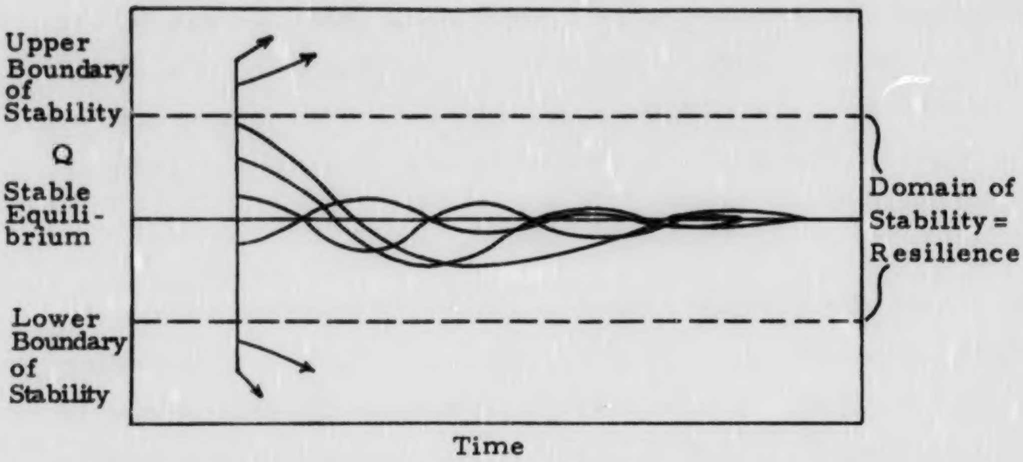

Upper Boundary of Stability
Q
Stable Equilibrium
Lower Boundary of Stability
Domain of Stability = Resilience
Time

Figure 3. An example of a system with a stable equilibrium in which stability is possible within distinct boundaries.

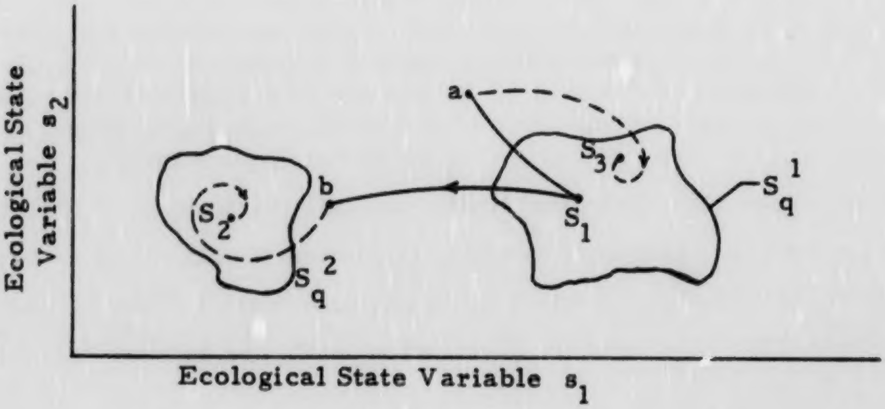

Ecological State Variable s_2
Ecological State Variable s_1
a
b
S_1
S_2
S_3
S_q^1
S_q^2

Figure 4. Second-order quality states as regions of second-order of ecological state space.

lake or stream is said to have a corresponding material processing capacity.

2. Reversible Pollution: If the input rate is such that the ecological state may eventually move outside the quality regions S_q^1, for example, but will eventually return to quality region S_q^1 once the stimulus is removed, or is "neutralizable" by a counter stimulus, they are said to be at a reversible pollution level. The clean up of Lake Washington is well known.
3. Nonreversible Pollution: If the input rates are such that the ecological states may eventually move outside equality regions S_q^1, for example, to the extent that the state cannot be returned to S_q^1 by reducing the stimuli, they are said to be at a nonreversible pollution level.

A crucial point is that the size and configuration of the stability domain can be altered as a result of perturbations of the system. With each successive perturbation, the system becomes less capable of absorbing additional disturbances (i.e., the size of the stability domain is decreased). In effect, then, resilience is a measure of the ability of the system to withstand shocks or perturbations. While incremental shocks or changes can be absorbed, the accumulative effect of small perturbations might reduce overall systems resilience. While the current state of the art precludes any formal mathematical treatment of the resilience concept, its use as a factor in defining carrying capacity shifts attention away from "optimum," "maximum," or "equilibrium" descriptions of systems behavior and toward descriptions of systems behavior near the boundary between stability and instability where environmental degradation is likely to begin. Holling and Orlans (1971) stress the need to understand "the complex nature of tradeoffs and limitations and options and resilience that characterize systems operating close to the carrying capacity of the environment."

While it is not yet possible to quantify the resilience of a complex system, the concept of systems resilience points out the importance of considering such things as boundaries, thresholds, tolerances, and limits in effective management of complex systems. Even though we lack the mathematical sophistication to directly apply the concept of systems resilience in analyzing the effects of various types of stress on the system, any definition of carrying capacity should incorporate such boundary-oriented concerns as limiting factors (environmental factors which physically or behaviorally limit growth, reproduction, or resource use of an individual, community, or activity) and trigger factors (factors which at a certain threshold set off a chain of events in an ecological or urban environmental system).

These basic ecosystem properties highlight the fact that the task of defining and determining carrying capacity must incorporate an understanding and analysis of system boundaries and processes. This realization is summarized by Holling and Goldberg (1971) as follows:

> It is this boundary oriented view of stability emerging from ecology that can serve as a conceptual framework for man's intervention into ecological systems. Such a framework changes the emphasis from maximizing the probability of success to minimizing the chance of disaster. It shifts the concentration from the forces that lead to convergence on equilibrium, to the forces that lead to divergence from a boundary. It shifts out interest from increased efficiency to the need for resilience. Most important, it focuses attention

on causes, not symptoms. There is now, for example, growing concern for pollution, but the causes are not just the explosion of population and consumption, but also the implosion of the boundaries of stability.

PROBLEMS IN DEFINING CARRYING CAPACITY DIMENSIONS

Description and analysis of environmental carrying capacity, as the foregoing discussions and examples indicate, must be performed within properly identified and dimensioned domains. The domains of key concern are spatial and temporal. The problems arise in that dimensions and boundaries of these domains in the human environments do not neatly map onto or correspond with the dimensions in the natural environments. This gives rise to the additional problem of making social and environmental trade offs.

The Spatial Domain

Simple one-dimensional point estimates of carrying capacity are neither realistic nor practical. All of the following examples illustrate that a broad spatial representation of capacity must be taken into consideration: Levels of population and employment, traffic flows of all types through the region, weather conditions, actual and potential socio-economic structure, technology (particularly in regard to the residual component of both production and consumption activity), transport systems, the price system including prices on goods with negative utility such as residuals, and the preferences of regional residents for environmental quality, economic growth, etc. In terms of the spatial domain of natural systems Cooper and Vlasin identify the problem as one of distribution of pollutants to prevent overloading (a boundary condition problem) which destroys the structural integrity of the natural-biological community. They note that

> Natural inorganics like heavy metals, synthetic compounds that are toxic (PCB's, nondegradable pesticides, etc.) and radioactive materials are often assimilated but result in organic products that have toxic characteristics to other biological organisms. The accumulation of these materials in the ecological system is a major threat to the aesthetic and human health characteristics of our environment. Distribution (dilution in space) cannot be considered a feasible solution to the waste disposal problems with these materials.

Hence, the definition must allow for natural-human resource trade offs in the spatial domain of at least two types: (1) For a given set of environmental standards there are trade offs among activities such as reduced employment--greater population, fewer people--greater vehicular traffic, etc., and (2) trade offs between standards or goals and economic activity such as reduced air quality standards and a wider range of fuel use, or between the rustic rural life characterized by low average income and the faster paced, congested urban situation with significantly higher incomes.

For a given set of standards, the price system will have an effect on carrying capacity. Two of the most pressing urban problems are congestion on the city's transport system especially at peak-use hours and air pollution. Both of these represent a failure of the market to efficiently allocate the scarce resources involved, namely road space and fresh air. In both cases, the effective marginal cost of the resource to the individual is zero, and, thus, it is not surprising that quantity demanded for expressways and for clean air exceeds the quantity supplied at that price. Through user charges for expressways and charges for discharge of pollutants into the atmosphere, the scarce resources could be more efficiently allocated. Highway toll charges that vary with the level of use would encourage the use of car pools or public transit, with the result of reducing the number of vehicles and increasing the average speed of all vehicles. Effluent charges would encourage the adoption of nonpolluting technology or investment in pollution control devices. The revenues from both types of changes could be used for social investment in highways, pollution control, or whatever else was deemed desirable, according to the preferences (i.e., taste for pollution) of the region's residents. As these tastes change, carrying capacity of the region will change. If people find that a cleaner environment is preferred to more income, they can vote or otherwise indicate this preference; and to the extent policy makers are sensitive to such pressure, rules will be changed. The identification of the optimal level of pollution (equivalently, the optimal level of resource "purity") stands out as one of society's most pressing problems and is also one that seems to defy efforts to measure quantitatively.

The Temporal Domain

Carrying capacity must also be considered in a dynamic or temporal context. Cooper and Vlasin find that expectations concerning time required for system response or achievement of goals is a fundamental difference between the natural and human environments. The natural environment works on an evolutionary time scale where "the criteria of success require survivorship for many generations." Thus, short-term decisions, such as those of the human environment which are usually oriented toward present generations, have a greater likelihood of being fatal.

In the human environment, the temporal perspective is also an important aspect of control and survival. Economic mechanisms stimulate technological advances and related investment, probably in response to the set of prices, and may lead to increases in carrying capacity over time. The development of internal combustion engines generating lower emission levels per RPM will allow greater traffic volumes in the region. Improved production processes will enable greater output from given input quantities, and will, thus, facilitate greater output without increased demand on the region's stock of resources. Improved technology in transportation (e.g., bigger and faster airplanes and trucks, traffic control devices, more efficient terminal facilities) will work toward increasing the average speed of movement of goods and people and will tend to lower per unit costs. Cities having well developed expressway systems for automobiles, for example, tend to be able to move traffic about and through the city at significantly higher speeds than cities without such systems. Viewing the temporal domain of socio-cultural institutions, Cooper and Vlasin point out that "urban planners develop twenty-five year master plans. Economists develop econometric models with eight to ten year projections. Politicians respond at six, four or two year intervals depending upon their election cycles. None of the control mechanisms currently existing in the human sector, however, deal with evolutionary or ecological time domains."

Environmental-Social Trade Offs

In summary, it seems clear that rather than defining carrying capacity as a certain level of population or some other point criterion, it must be defined in terms of a rather complicated function or set of functions which would include a number of regional characteristics and economic parameters, and would make explicit the possible trade offs that are implicit in the definition. This requires a representation then of "the set of social trade offs between the layman's concept of environmental quality and the degree to which human society desires or needs to utilize the production and assimilation capabilities of the natural environment." (Cooper and Vlasin).

CARRYING CAPACITY--A HUMAN ORIENTED DEFINITION

To date, the concept of carrying capacity has mainly been used and applied in terms of ecological systems. The notion of an upper bound on population has been widely applied as a tool for the management of natural communities (ecosystems). Generally, the upper bound on the population density of a particular species has been set as the maximum population density for that species which can be supported by a given environment (habitat, ecosystem) without degradation. Many of the difficult problems of environmental management arise, however, in the urban-regional context. Since urban systems interface with natural systems and since natural systems are a part of urban systems, the concept of carrying capacities in this setting is in need of an enrichment in definition and interpretation.

When applied to human activities, the carrying capacity theme becomes much more complex. In examining the critical interrelationships between human and economic activity and the changes wrought upon resources and the environment of a region and their capacity to accommodate such change, it can be seen that the concepts associated with the term "carrying capacity" must be greatly broadened to find appropriate application in the realm of human activity. Rather than a single fixed number being rigorously established as a "population carrying capacity," it suggests that we must be concerned with a number of resource limits and environmental factors that may act as constraints or damping forces in the dynamic interaction of population growth, related socio-economic activity, the resource base, and the environment as an assimilator of waste by-products. Attention, therefore, is directed toward viewing the regional environment as a support system for numerous, interdependent, and frequently competing activities and subsystems, where the determination of carrying capacity rests upon desired human and environmental quality levels which are circumscribed by a wide variety of political/institutional, physical/biological, and social/cultural constraints.

From this and the previous discussion it should be clear that a human oriented carrying capacity cannot be developed in a simple, single, numerical measure. It is not only a multidimensional concept but it is subject to constant change and modification particularly as technological improvements are made and as rules change due to pressures from the region's residents.

A Normative Definition of Carrying Capacity

The basic elements involved in the definition of carrying capacity hinge on the interrelation of resources, processes which convert those resources to desired outputs, and waste products and residuals which must be assimilated back into the resource base with future effects on quantity and quality. This simplified picture of carrying capacity is diagrammed in Figure 5.

Viewing Figure 5 as a closed system, carrying capacity may be seen as the ability to produce desired outputs (goods and services) from a limited resource base (inputs or resources) while at the same time

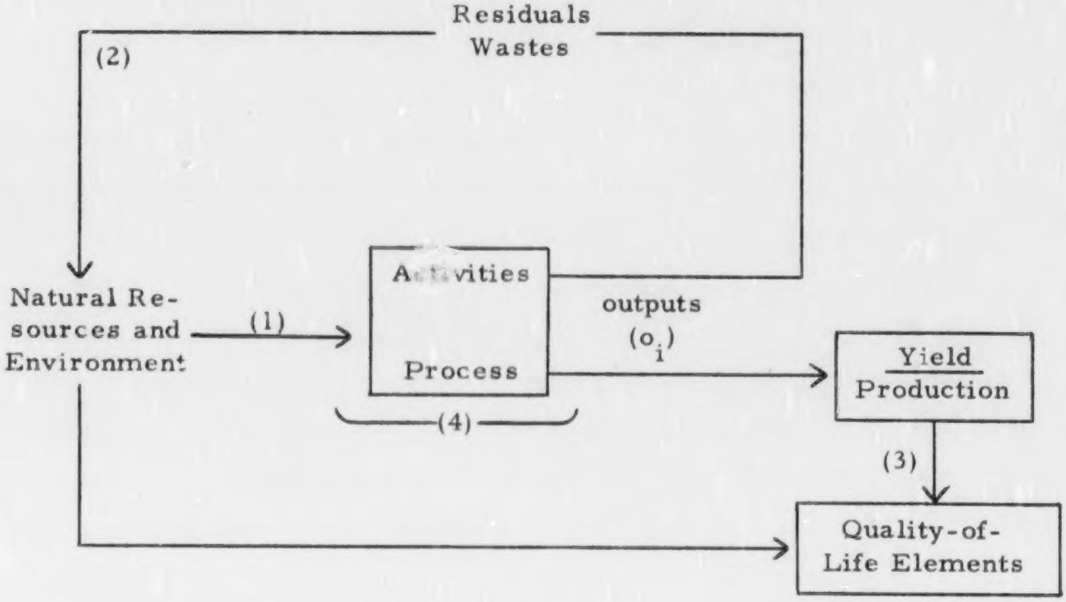

Residuals
Wastes
(2)
Natural Resources and Environment
(1)
Activities
Process
(4)
outputs
(o_i)
Yield
Production
(3)
Quality-of-Life Elements

Figure 5. Elements of carrying capacity.

maintain desired quality levels in this resource base. For an open system, the definition would further have to allow for import of both resources and goods and services, and the export of production and residuals. The basic diagram of Figure 5 yields four dimensions which are relevant to the overall measurement of carrying capacity.

1. Resource-production relations: The capacity of available resources to sustain rates of resource use in production.
2. Resource-residuals relations: The capacity of the environmental media to assimilate wastes and residuals from production and consumption at acceptable quality levels.
3. Infrastructure-congestion relations: The capacity of infrastructure resources (distribution and delivery systems) to handle the flow of goods and services and resources used in production.
4. Production-societal relations: The capacity of both resources and production outputs to provide acceptable quality-of-life levels.

Working from these four relationships, then, human carrying capacity is defined as follows: Carrying capacity is the level of human activity (including population dynamics and economic activity) which a region can sustain (including consideration of import and export of resources and waste residuals) at acceptable "quality-of-life" levels in perpetuity.

An Operational Definition of Carrying Capacity--The Human and Natural Environmental Trade Offs

The high degree of interrelation among resources, environmental media, and desired quantity and quality states for human and associated socio-economic activity underscores the fact that trade offs must inevitably be made among desired production-consumption levels, resource uses, and a cleaner, healthier and more pleasant environment. From this perspective, carrying capacity must be interpreted as a variable which is essentially socially determined within our understanding of economic, social, and environmental values and their relative contribution in maintaining quality-of-life levels. This dual perspective required in providing an operational meaning to the definition of carrying capacity is presented in the flow diagram of Figure 6. The diagram illustrates that the working use of the carrying capacity definition requires a series of adjustments to reconcile the capacity limits related to quality levels of the natural environment and desired levels of consumption of goods and services by society. For example, some of the key issues in examining these trade offs in acceptable levels of "carrying capacity" are:

1. What are the costs and benefits of developing (preserving) a resource or relaxing (enforcing) an environmental standard? (For example, reducing air or water quality standards in the face of the fuel shortages in order to allow particular resource developments.)
2. What are the ramifications of removing a capacity constraint through new or improved technology, learning, or new resource discovery?

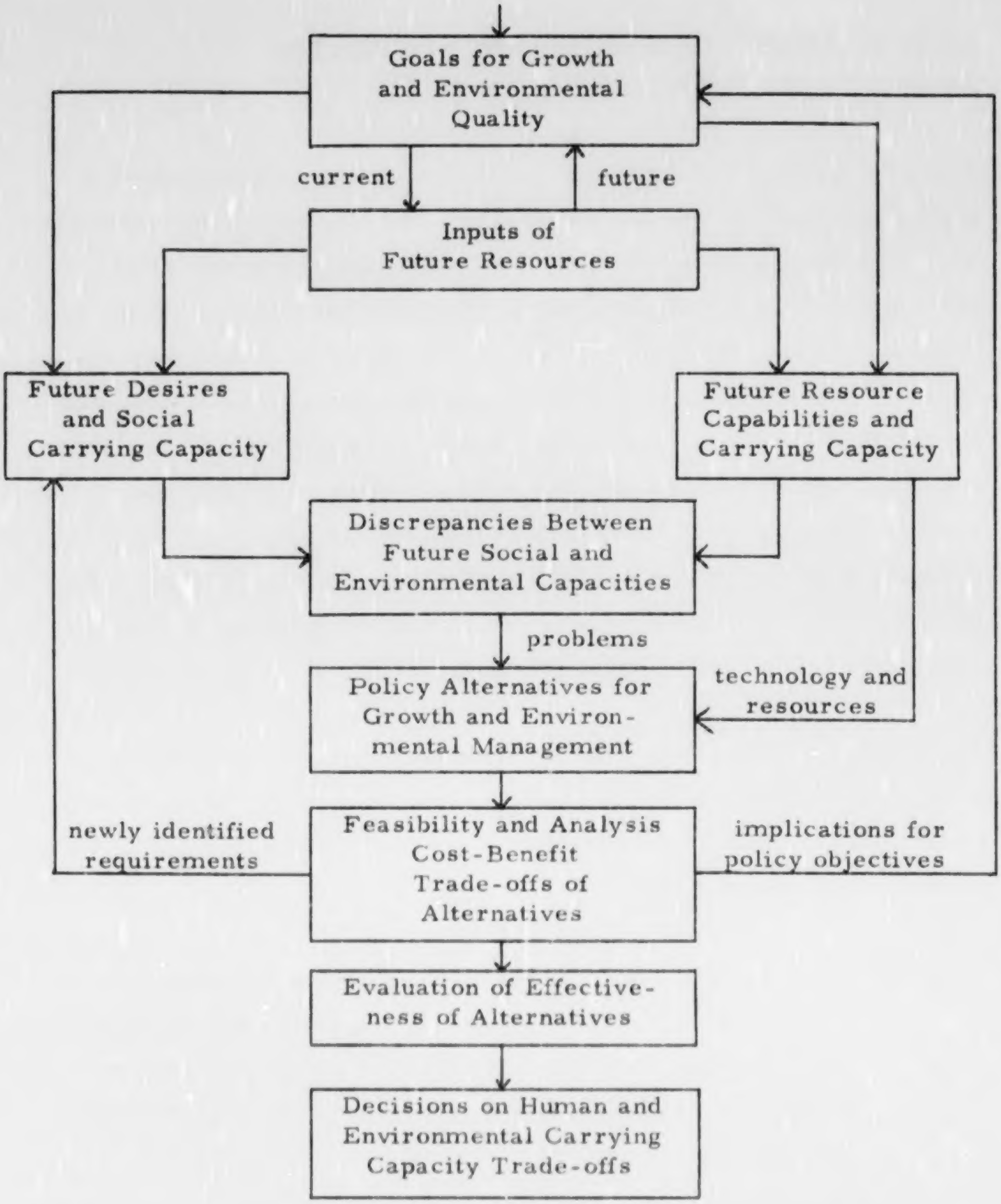

Goals for Growth and Environmental Quality
current
future
Inputs of Future Resources
Future Desires and Social Carrying Capacity
Future Resource Capabilities and Carrying Capacity
Discrepancies Between Future Social and Environmental Capacities
problems
technology and resources
Policy Alternatives for Growth and Environmental Management
newly identified requirements
Feasibility and Analysis Cost-Benefit Trade-offs of Alternatives
implications for policy objectives
Evaluation of Effectiveness of Alternatives
Decisions on Human and Environmental Carrying Capacity Trade-offs

Figure 6. Flow diagram for an operational definition of carrying capacity.

The adjustments between future desires or social capacities and resource capabilities in operationalizing the normative definition of carrying capacity are partly technical questions where analytical models can usefully be applied and partly value questions where social and political mechanisms are required. The integration of the two must be accomplished within a carrying capacity-based planning and decision making process. Such a process is formulated and described in Chapter 5. The implications of these carrying capacity definitions direct attention to important issues in managing urban-regional growth in terms of efficiency of energy and material transfer, handling of wastes and by-products, and capability of human and natural environments to support activities.

SECTION IV

RESOURCE DESCRIPTION AND CARRYING CAPACITY

RESOURCE CLASSIFICATION AND CHARACTERISTICS

Traditionally, resources have been viewed either as elements of the natural environment or as inputs to economic production. In urban areas, where much of the living environment is essentially man-made and serves as a means of organizing man's activities, it appears that our definition of resources and related environments is much too narrow.

In extending the concept of resources in examining the capability of a region to sustain existing and proposed activities, consideration must be given to aspects of three resource systems--character and extent of the natural resources, the infrastructure resources and functions of urban areas, and the social-cultural resources of people and institutions--which circumscribe the domains for carrying capacity in a region. The relation of these systems to the capacities of natural and human environments is diagrammed in Figure 7.

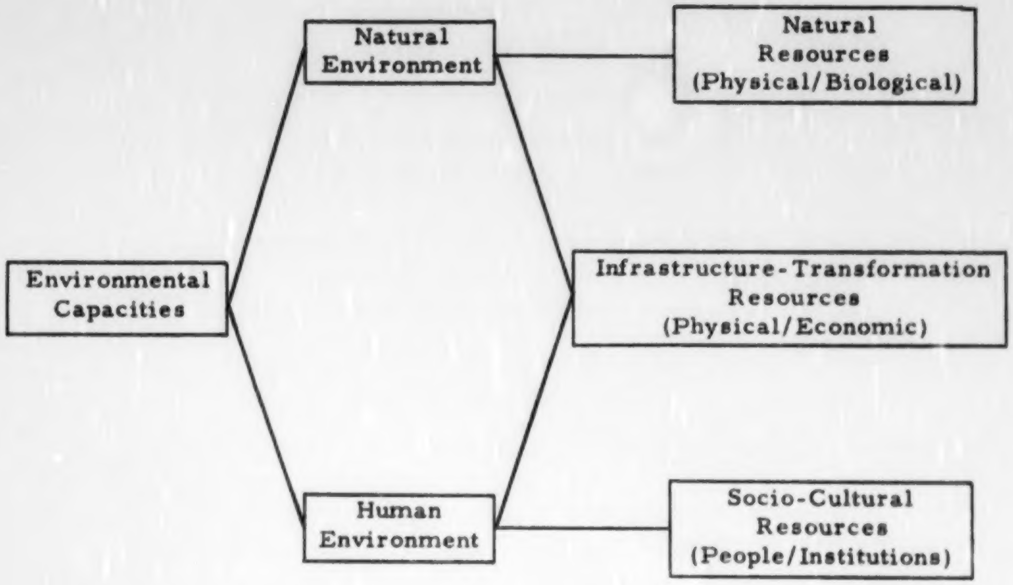

Natural Environment
Natural Resources (Physical/Biological)
Environmental Capacities
Infrastructure-Transformation Resources (Physical/Economic)
Human Environment
Socio-Cultural Resources (People/Institutions)

Figure 7. Environmental-resource relations.

These resource systems might be thought of as the basic building blocks of a region, as illustrated in Figure 8, in which each part of the structure interrelates with the others in establishing carrying capacity.

In determining the resource base, quantity and quality are two resource attributes that are inextricably connected so far as carrying capacity for a particular activity or use is concerned (e. g. , volume of water of quality for drinking, or for cooling; space and transport network capability for movement of vehicles, or institutional mechanisms for preserving open space).

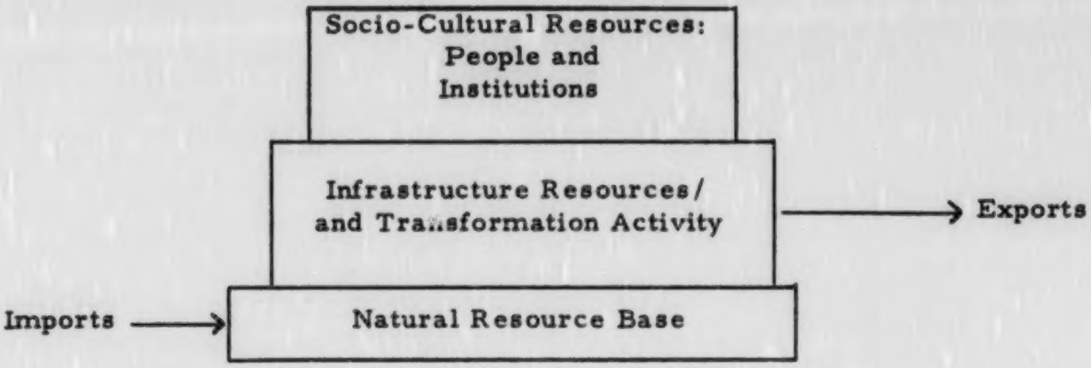

Socio-Cultural Resources:
People and
Institutions
Infrastructure Resources/
and Transformation Activity
Exports
Imports
Natural Resource Base

Figure 8. Resource systems in regional structure.

From the perspective of carrying capacity, rather than assuming the usual land, water, and air delineations, the description of natural and human resources environments (see Perloff, 1968) might be elaborated along the following lines:

Ambient resources:	Air, water, open space, quiet and noise zones, sunlight exposure
Spatial resources:	Underground space, available and transitional surface space, airways space
Infrastructure and distributive resources:	Transportation, water and water distribution, wastewater collection, energy (electricity and gas) distribution, communications
Ecological resources:	Green plants, nongreen plants, animals
Socio-cultural resources:	Educational and cultural facilities, health services, security services (fire, police), recreation services, housing stocks

Economic resources:	Raw materials for production inputs, capital, labor
Amenity resources:	Seashores, scenic areas, contiguous natural areas (mountains, deserts, lakes), open space

Some attributes or characteristics of these classes or types of urban resources which enter into an assessment of their capacity to support a particular activity or changes in sets of activities are displayed in Table 1.

Relative to these resource descriptions, the environmental planner and manager must seek to understand such questions as: What are the relevant resource components? How do they function? How do they interact with and influence other components, or conversely, how are they influenced by other components? What factors control levels of environmental quality and how do proposed plans or actions affect those factors? The classifications in Table 1 provide insight into such questions about the function and structure of urban environmental resources and their interactions with one another, and are central to specifying the domains of environmental carrying capacities for urban regions.

Renewability

The quantity and quality of a resource is closely related to its characteristics of renewability or nonrenewability. Stock resources, such as mineral deposits, fossil fuels, and available land, are essentially fixed in quantity and in that sense nonrenewable. The capacity of such

Table 1. CONSIDERATIONS IN RESOURCE CLASSIFICATION

	Renewability		Mobility		System			Ownership			
Class	Stock	Flow						Private Control	Public Control		
Resource	Nonrenewable	Renewable	Mobile	Immobile	Natural	Infrastructure	Social Cultural		Local	Regional	National
Ambient		X	X		X				X	X	X
Spatial	X			X	X			X	X	X	X
Transformation Distributive		X	X	X		X		X	X	X	
Ecological		X	X		X			X	X	X	X
Socio-Cultural		X	X	X		X	X	X	X		
Economic	X	X	X	X	X	X	X	X			
Amenity	X			X	X		X		X	X	X

resources for supporting urban systems, therefore, depends on rates of use or exploitation, the possibilities for salvage and recycling, and the development of substitutes. Naturally renewed resources (natural vegetational and animal growth) and flow resources (solar radiation and natural cycles for water and other elements) have renewable characteristics in which process rates determine the quantity and quality available in a given time period. Capacity of renewable resources depends on the care and efficiency of man's intervention in the use of the resource without upsetting or destroying the natural processes which assure the resource availability.

Mobility

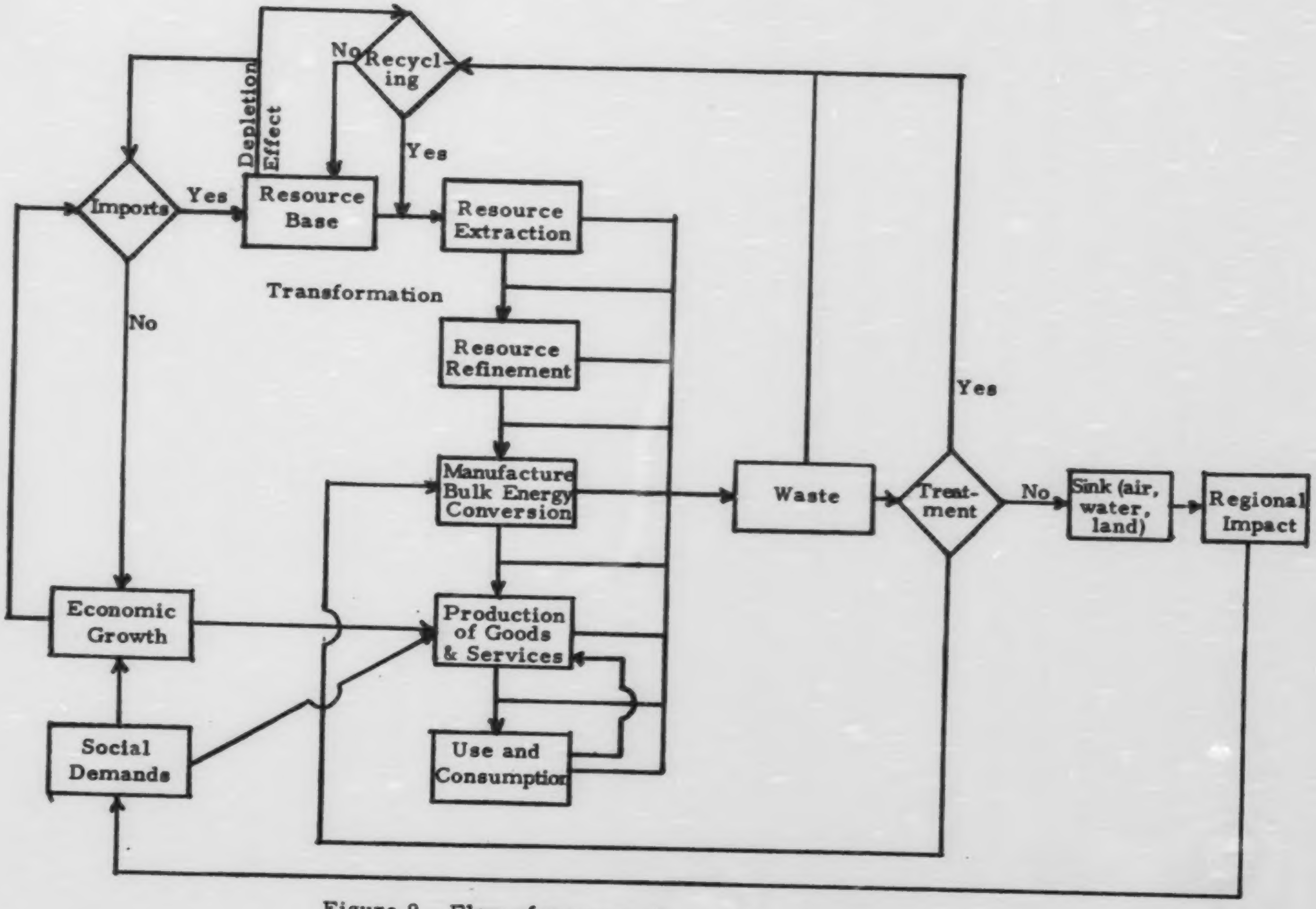
Mobility, as it affects the spatial distribution of resources, is an important part of identifying which resources are part of the urban region itself. Drawing boundaries around the urban region in order to geographically circumscribe the resources which contribute to its carrying capacity may be a difficult and sometimes arbitrary task. Electrical energy, water, and fossil fuels are resources which are often situated large distances from actual centers of urban activity. Should they be considered as external or imported resources? This question raises the broader issues of environmental quality relations between areas of resource extraction or production and areas of resource use. The carrying capacity concept recognizes that the interface between the city and nonurban areas has become more explicit, particularly in the couplings established through resource development, energy production and transfer, pollution outputs, and deterioration of contiguous agricultural and recreation lands due to urban sprawl.

Systems

Description of resources systems provide a basic structure for determining how growth, as measured against resource capacities, will affect regional environmental quality. Basic components of resource systems are briefly noted in the following.

Natural Resources System--

Although a logical starting point, it is difficult to define carrying capacity completely in terms of a finite resource base, since a resource is important only as it is transformed into an array of services. It does not represent a single service or output in most cases. The outputs and services of concern in terms of system carrying capacity are (1) the production of goods and services at levels consistent with society's desired quality of life, and (2) the capacity to assimilate wastes and residuals into receiving media at levels which meet acceptable standards of environmental quality. The impact on natural resources of providing these services is diagrammed in Figure 9. Of particular interest in the flow chart is the natural resource base as a "sink," which is usually a common pool resource. In terms of residual assimilative capacities, many regions are apparently operating at levels far beyond what could be maintained within a strictly closed regional system. The unsolicited import and free export of harmful residuals from production and consumption are of particular concern in analyzing carrying capacity since they have not responded in a satisfactory manner to private incentives as expressed in the market. Also, the problem of trade offs is clear in examining the outputs, since the consumption



Recycl-
ing
No
Yes
Depletion
Effect
Imports
Yes
No
Resource
Base
Resource
Extraction
Transformation
Resource
Refinement
Manufacture
Bulk Energy
Conversion
Production
of Goods
& Services
Use and
Consumption
Economic
Growth
Social
Demands
Waste
Treat-
ment
Yes
No
Sink (air,
water,
land)
Regional
Impact

Figure 9. Flow of resource from and to the natural system.

of goods and services which contributes to quality of life are the same activities which generate the wastes which reduce quality-of-life levels. The proper balance and trade offs between these in accommodating growth is one of the central issues in carrying capacity.

In examining natural system structure, it appears that there will usually be a hierarchy of limiting factors for any region, although only a few resources will actually be the effective constraints in limiting growth and development at any one point in time. These factors may be on the resource input side, the waste assimilation side, or else a small number of factors will act in combination to present limits to the region. These factors determine natural resource system limits for the region, and affect the distribution of population and activity across the region.

Infrastructure Resources System--

Superimposed upon the mosaic of natural (physical and ecological) resources of a region is the domain of urban infrastructure as a resource system. The composite of urban activities, both public and private, such as education, health, industry, commerce, recreation, agriculture, and personal services contribute to a set of regional outputs of physical products or elements which contribute to quality of life. These activities are linked and supported by the infrastructure and resource distribution systems of the region.

The existing regional infrastructure represents the carrying capacity, at least in the short run, of a region's capital stock to provide or distribute needed services, such as transportation, energy, water, and waste disposal. Hence, the rates of flow or service delivery are limited by the capacity of the system. Some of the elements of regional infrastructure which have important interrelations with the carrying capacity of the region are noted in Table 2.

Table 2. DESCRIPTIONS OF REGIONAL INFRASTRUCTURE

Type	Service/Output	Descriptive Dimensions
Public Utilities	Water supply, energy distribution (electricity, gas), communications	Sources and location service area, size and scale, peak loads
Public Services	Schools, health care, recreation, cultural and entertainment	Location, population served
Land Utilization	Housing, transportation	Quantity and quality of housing stock, rates of deterioration, peak loads existing capacity, network and service characteristics
Resource Transformation and production	Industrial production, commercial and marketing	Capital and investment depreciation rates
Residuals Management	Sewer systems, solid waste disposal, air emissions controls	Air, land, and water quality standards, waste loading, media characteristics

The current capability of the infrastructure and the resources they distribute to sustain activity is a key aspect of the "carrying capacity" of an urban region, and, as such, represents short and medium run constraints on regional quality growth.

Social-Cultural Resource System--

People and institutions represent the third important resource capacity system, which operates to govern the human environment. Institutional and individual values as reflected in present or desired life styles of the residents of regions should tell importantly in determining quality aspects of regional growth. Social scientists have argued that social and economic development is best measured by observing the latitude and distribution of choices available to a given population. To prespecify capacity limits on selected system outputs without consideration of social-cultural capacities can narrow this range of choices or possibly expand the range for particular subsets of the population at the expense of others.

Ownership: Economic and Social Costs

The classical concept of common property or "free good" resources has little validity in terms of carrying capacity for sustaining regional activity and growth. In the reckoning of social accounts, there is now a high cost associated with maintaining the quality of ambient resources--air, water, etc. The industrial firm dumping wastes directly to a stream, airplane flightpaths over residential areas, the individual automobile adding to congestion and air pollution, the building that blocks out the sun are all examples of individual actions contributing to a deterioration in environmental quality for the whole of society (Perloff, 1968). What levels of activity in use of common resources should or can be permitted is certainly a question in the domain of the carrying capacity concept.

RESOURCE CAPACITY CONSIDERATION

Carrying capacity, as viewed from the standpoint of resource impacts, has two distinguishable but related meanings, both of which seem to be important for management purposes. These are: (1) The capacity of the environment to supply resources for certain activities (supportive capacity) and (2) the capacity of the environment to act as a sink for wastes produced from certain activities (assimilative capacity). The "sustained yield" concept pertains to both meanings, but has been used most often in relation to the former; "systems integrity" concepts (e.g., resilience, stability) also apply to both meanings. The general relationship of the two meanings is illustrated by the diagram in Figure 10.

Taking into account the interactions with other activities, the diagram appears as in Figure 11.

The following provide some simple integrating examples of supportive and assimilative capacities of the two broad classes of environment.

(1)	Natural environment Supportive capacity	Capacity of an aquifer (or other water source) to support water needs of a small community

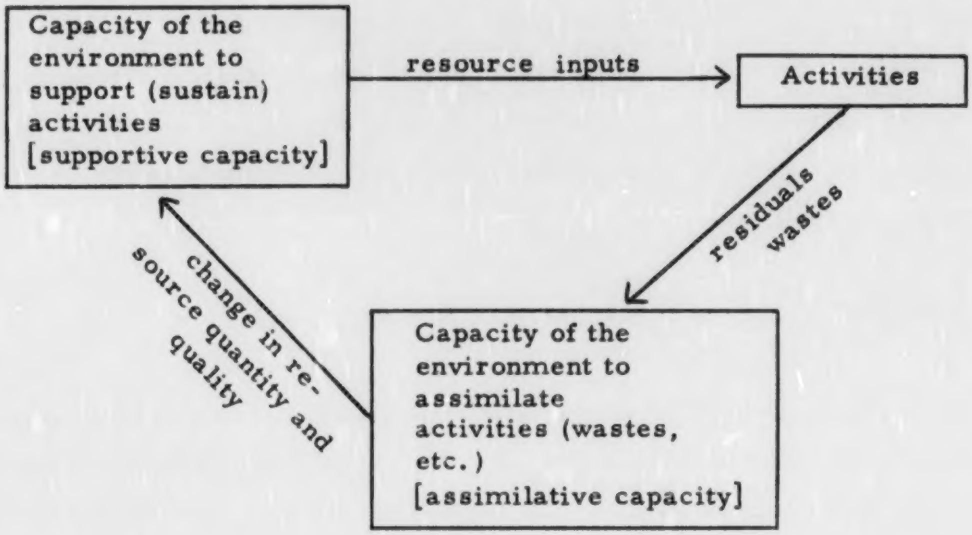

Capacity of the environment to support (sustain) activities [supportive capacity]
resource inputs
Activities
residuals wastes
Capacity of the environment to assimilate activities (wastes, etc.) [assimilative capacity]
change in resource quantity and quality

Figure 10. Relation of supportive and assimilative capacities.

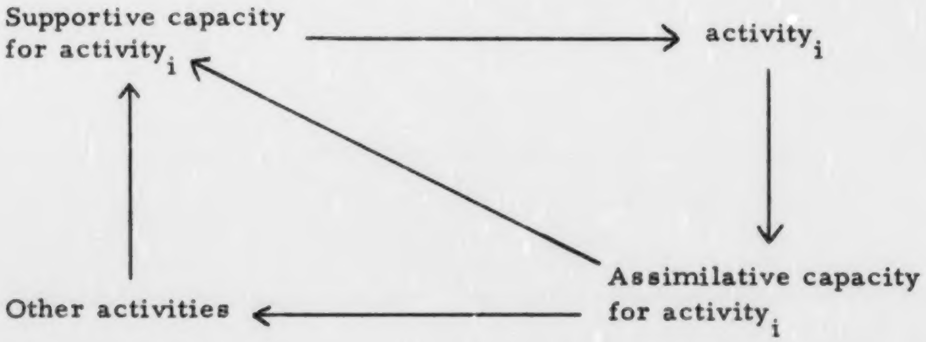
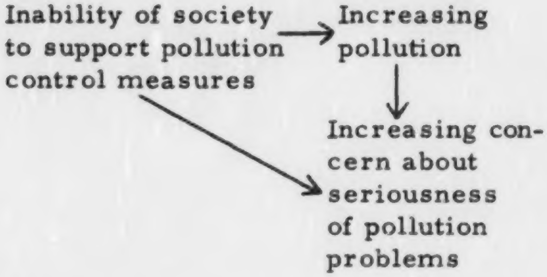
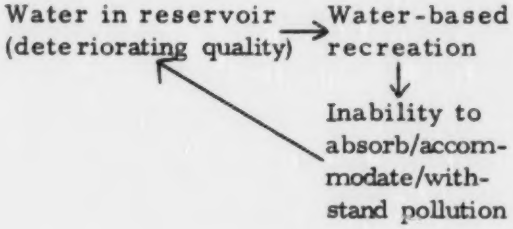

Supportive capacity for activity$_i$
activity$_i$
Assimilative capacity for activity$_i$
Other activities

Figure 11. Activity interactions and carrying capacity.

(2)	Natural environment Assimilative capacity	Capacity of a lake to assimilate municipal/industrial/agricultural wastes
(3)	Human environment Supportive capacity	Capacity of a community tax base to support schools and other public services in a suburbanizing area
(4)	Human environment Assimilative capacity	Capacity of recreationist to assimilate crowding and congestion (and other encroachments) at recreational sites
(5)	Example of interactive effects between supportive and assimilative carrying capacity (human environment)	 Inability of society to support pollution control measures Increasing pollution Increasing concern about seriousness of pollution problems
(6)	Examples of interactive effect between supportive and assimilative carrying capacity (natural environment)	 Water in reservoir (deteriorating quality) Water-based recreation Inability to absorb/accommodate/withstand pollution

Systems Capacities

Approaching the description of environmental carrying capacity at the resource level (natural, infrastructure, and socio-cultural) yields the following interpretation:

Resource Capacity--

Resource capacity is basically a biological and resource flow definition. Capacity is examined in terms of the levels or input rates for an activity that can be withstood by the biota or the resource flow systems and still return to an unimpaired state. Essentially this suggests a nonimpairment criterion for establishing levels of use which can be sustained for an indefinite period of time without altering or degrading the resource. The underlying objective, then, is achieving a maximum sustained yield for a given activity. The important factors in analyzing resource capacity are the ability of the resource to produce the kinds of services required, and the ability of the biota or flow system to recover after peak use (for example, the ability of air and water to assimilate certain pollution waste loads over a period of time without permanent deterioration of ambient quality conditions).

System Constraint Capacities--

System constraint capacities are concerned more with the physical limits of resources or of resource processing and use systems. Physical resource limits would be considered in terms of nonrenewable stocks or resources such as mineral deposits, fossil fuels, and available land (in the short and medium run), and the rates at which such resources are being developed and used. For the resource processing infrastructure, the capacity for use of both nonrenewable and flow resources may also be limited by the capability of the present system to transform and utilize them. For example, a certain forest area might be producing a net annual increase in timber which is greater than can be harvested on a sustained yield basis because it is inaccessible from the current transportation system. The objective indicated by this definition is efficiency in resource use and in the management of resource processing systems.

Social/Psychological Capacity--

The determination of social/psychological carrying capacity depends upon a wide variety of political/institutional, physical/biological, and social/cultural constraints. Social/psychological carrying capacity is related to the overall levels of satisfaction experienced by users or other affected individuals resulting from resource management practices. Social capacity is stated in terms of maximum number of use-units (e.g., people, vehicles, etc.) that can utilize available resources during a specified period of time for one or several activities while providing a satisfactory experience for the users. One operationalization of this goal in determining a "satisfactory experience" might be to maximize the total user satisfaction. Before determinations can be made about levels of "satisfactory experience," the kinds of experience the resource is expected to provide must be established. A particular resource or group of resources may be capable of providing for several different types of activities. Some of these activities will compete for the resources, while others may be compatible. Almost inevitably, this will require a management decision as to which resource use or combinations of uses will be pursued. An example would be whether a particular tract of land should be zoned and managed as open space or used for various kinds of residential and commercial development. Deriving a set of management objectives must take into consideration the feasibility of the objective in terms of resource capacity and system constraint capacities.

The aspect of "satisfactory experience" or user satisfaction is a function of individual attitudes with respect to the management objectives in question. In this context the question becomes "How many people can be handled in an activity at one time before the quality of the experience is lost?" or stated another way, "What number of people maximizes the total satisfaction in the use of the resource for a particular experience?"

SUMMARY

A general and broad picture of resource description in relation to carrying capacity with regional structure and forces of change and growth is presented in Figure 12. The figure illustrates the highly interrelated nature of resources described in this chapter in determining and measuring regional carrying capacities.

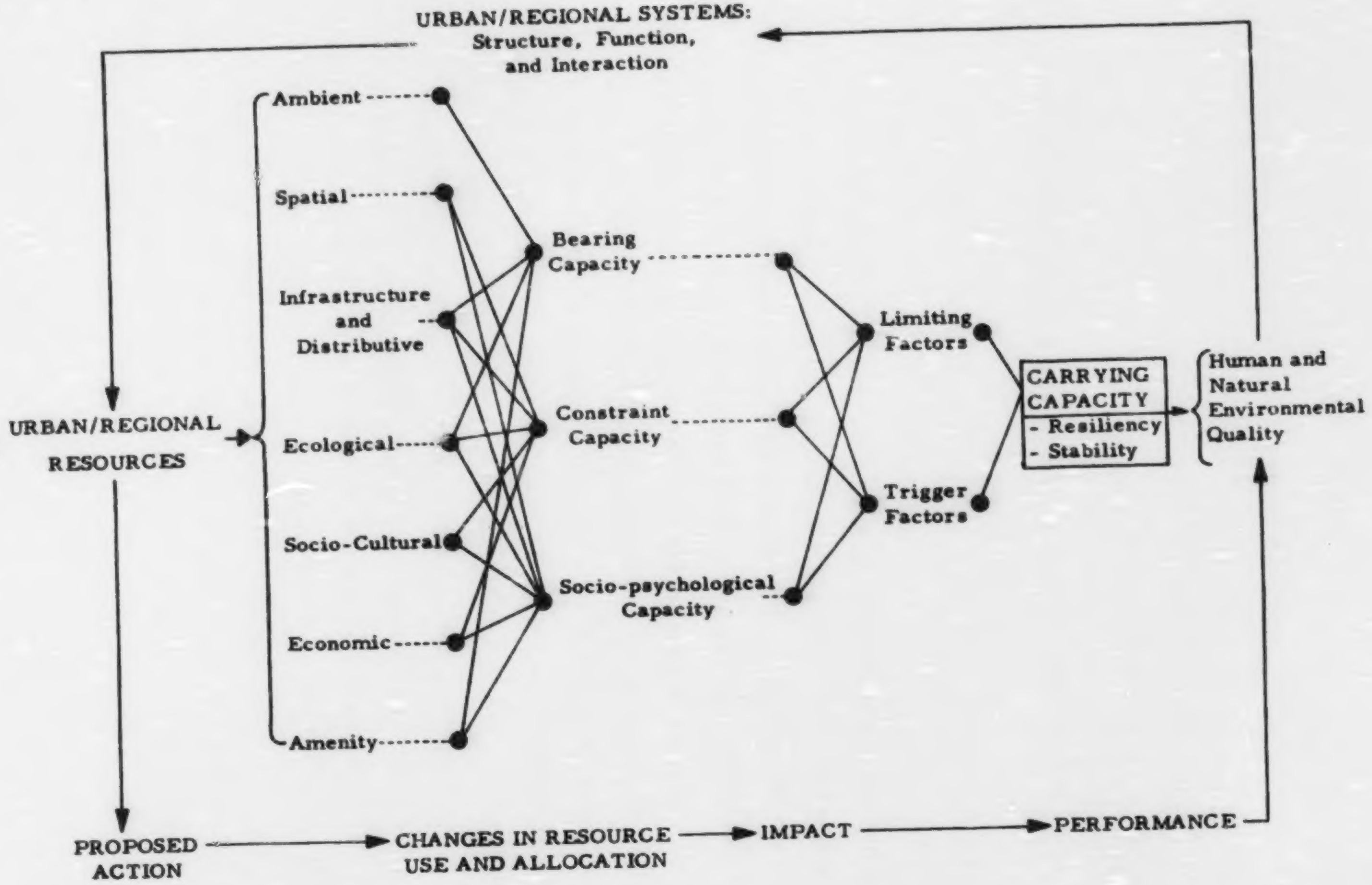

URBAN/REGIONAL SYSTEMS:
Structure, Function, and Interaction
URBAN/REGIONAL RESOURCES
Ambient
Spatial
Infrastructure and Distributive
Ecological
Socio-Cultural
Economic
Amenity
Bearing Capacity
Constraint Capacity
Socio-psychological Capacity
Limiting Factors
Trigger Factors
CARRYING CAPACITY
- Resiliency
- Stability
Human and Natural Environmental Quality
PROPOSED ACTION
CHANGES IN RESOURCE USE AND ALLOCATION
IMPACT
PERFORMANCE

Figure 12. Overview of resource-carrying capacity relationships.

SECTION V

REGIONAL STRUCTURE AND CARRYING CAPACITY

INTRODUCTION

The potential of a region to support a human population appears to be significantly related to its structure. Regional structure, in turn, can vary widely in its temporal and spatial dimensions because of differences in natural and man-affected capabilities for production, consumption, and assimilation. The production and assimilative potential of natural environments tend to be highly responsive to energy input (solar) and the availability of moisture such as in humid, semitropical regions. Their potential for sustaining human activities is considerably less in cooler-drier regions where human environments tend to locate and grow. Assessment of regional structure as it may influence carrying capacity includes a knowledge of the magnitude and diversity of natural and human environments and the distribution of activities within these environments over time and space. In the sections which follow, regional structure of the human environment will be examined in terms of alternative spatial contexts and in terms of the composition and growth of activities in response to both exogenous and internal factors.

SPATIAL CONTEXT FOR EXAMINING REGIONAL CARRYING CAPACITY

The selection of a spatial context for defining carrying capacity may be fully as important a consideration as the selection of variables (inputs, outputs) which comprise it. Virtually all definitions of regions fall within three main categories. These categories or approaches to regional delineation are defined in terms of homogeneity, nodality, and programming or policy.

Delimitation based on homogeneity stresses the similarity of one or some combination of physical, biological, social, economic, and other features which characterize a region. For example, regions could be delineated on the basis of physical characteristics by classifying them in accordance with dominant physiographic features, resources, and climate. Social characteristics might include such things as attitudes, race, and religion. Important in the context of carrying capacity are the economic features. These might include regions with similar socio-economic structures, homogeneous patterns of consumption, and/or production. Product specialization and income levels serve as important economic characteristics which are often used for defining regional economic conditions.

Delimitation based on nodality emphasizes the dominance of the urban center of a region. Focus is placed on the interdependence of different activities within the region, rather than interregional activities or relationships between homogeneous regions. Nodal regions are composed of heterogeneous units which have close functional interrelationships. Such functional interconnections are typified by flows of people, goods and services, communications, and traffic. These flows do not occur randomly over a region, but rather the heaviest flows tend to polarize towards and from a dominant central city or nodal point.

Finally, regional definition based on a *programming* or *policy* focus depends heavily on administrative coherence usually coincidental with recognized political subdivisions and units of economic decision making. Implementation of any overt regional policy or management concept demands a capability for action. Responsibility for such action ordinarily rests with recognized governmental units which may or may not be coincident with important components of carrying capacity. This points to a possible trade off between the ideal policy region for which carrying capacity is defined and the political jurisdiction under which management may be feasible. If carrying capacity is defined indiscriminately without regard to functional linkages between separate spatial units, then information derived from it may be of very little value because it cannot be implemented.

Regions defined on the basis of nodality and on the basis of policy and programming are merely utilizing special cases of the homogeneity approach. A program or policy region is essentially homogeneous in being entirely under the jurisdiction of a few special governmental or administrative agencies. Nodal regions, on the other hand, are homogeneous in that they combine areas dependent on a specific central city in some trade or functional sense. Ultimately, homogeneity with respect to statistical compilations and in terms of policies or programs being applied may be the operational determinants of regional boundaries. Regions defined on the basis of combining units with uniformly homogeneous characteristics should still exhibit a polarization of flows between contained central cities or nodes. Whether the analyst directs his attention to the homogeneous features of the region or to its nodal characteristics depends primarily upon the nature of his inquiry. If prime concern is directed to the planning problem of a single region, such as definition and implementation of carrying capacity, it will be necessary to concentrate on the polarization aspects and the interdependence between separate subregional units. In contrast, if interest is directed to the interregional relation of a particular areal unit, such as the transference of business cycles from one region to another, uniformity in their definition may be most appropriate.

Thus, it becomes obvious that the choice of an ideal region is constrained by the purposes for the delimitation of sets of regional boundaries and by the overall structure and degree of integration of regional systems. Further, the concept of "ideal" region can be expected to change in relation to the elements of carrying capacity which are the focus of policy. For example, the boundaries for ecological spaces such as air sheds, hydrologic basins, aquifers and ecological land areas seldom coincide with the boundaries of any single decision-making unit, whether public or private. Under these circumstances aggregation across separately identified units of government to approximate an integrated ecologic-socio-economic region may be required in order to internalize the full implications (gains and losses) associated with a policy decision.

A suitable socio-economic building block which could be used for this purpose is the functional economic area (FEA). Such areas are usefully viewed from the perspective of a single region to the interrelationships within a broader metropolitan or national setting. Basically these are employment demand regions which act as reasonably independent units within a more complex spatial economic organization. A basis for defining these "ideal" economic regions derives from a recognition of the following: 1) Essential services and a major portion of employment are provided by a central city or nodal center. 2) The time cost of distance between central city and residence in the surrounding area defines the outer perimeter of an areal unit. 3) Scale economies in providing essential services determine viability of the centers. The minimum number of persons living within the region must be large enough to capture these economies. Regions so defined are homogeneous in the extent to which their internal organization of residentiary activities are essentially similar. At the same time, they may be strikingly heterogeneous in terms of basic activities, political organization, and resource base.

Most early applications of the FEA-delineation were limited to predominantly rural areas. However, it seems not to be restricted to that particular domain because the internal structure of an FEA is essentially the same, whether in an urban or a rural setting. Large metropolitan areas and surrounding hinterlands are merely FEA's arranged in clusters of varying density. Thus it appears that carrying capacity derived questions which transcend conventional political boundaries could be examined within the context of an integrated region without losing accountability at a functional or local level. However, such aggregations merely facilitate analysis and decision making at an appropriate level and provide no assurance that "integrated" decisions will follow mainly because of the impracticality and nonexistence of formal regional governments.

REGIONAL ECONOMICS AND CARRYING CAPACITY

Economic Composition of a Region

The economic structure of the region, essentially the composition of employment and/or output from the various industrial sectors, will influence and be influenced by any administratively set carrying capacities. If environmental standards for air and water quality are fixed, then regional activity in one or several heavy polluting industries will involve significantly less total employment and, of course, population within the framework of those established capacities than would be the case if activity was concentrated in the relatively pollution-free sectors. Clearly, from the production side it would take many times the pollution generated by one steel mill or copper smelter. However, things might be different on the consumption side. The pollution generated by one banker's consumption habits would probably approximate or exceed that of one steel worker.

The spatial structure of the region's economy will also influence carrying capacity and will be significantly influenced by the transportation network. If employment centers are scattered about the region rather than being concentrated in, say, the central business district, congestion would tend to be reduced on the regional highway system and residuals from both production and consumption (i. e., automobiles) would be more generally diffused in the region's atmosphere and therefore more likely to be dissipated. Furthermore, to the extent that workers sought residential locations near their place of employment, the scattered employment center construct would result in less miles driven (at least in commuting to work), less energy consumed, and lower levels of residuals discharged.

Conversely, such a dispersed spatial structure is antithetical development of mass transit systems that are generally more efficient than automobiles in terms of fuel consumed and pollutants discharged per passenger mile. Only when economic activity and commuting flows are concentrated in one or two places can mass transit systems generate sufficient volume to be profitable, and even cities having this spatial concentration have found it exceedingly difficult to keep their transit systems operating without subsidies. In any event, capacity definitions must include a measure or index of the degree of dispersal or concentration of the region's economic activities.

The size of the region as measured by population and employment will also influence economic structure. Virtually all market-oriented activities have minimum or threshold population levels that must be achieved before they can be profitably engaged in. For example, one does not usually find a department store in a community of 500 residents, but one or two gasoline service stations are usually in evidence. Efficient production of many goods requires a plant size above some minimum level, and must only locate in an area where there exists sufficient labor to staff and operate it. The city of 500 mentioned before is unlikely to be the site of a steel mill. Likewise, transportation system development will also be a function of size. Commercial airline or railroad service is not generally offered to cities in the absence of subsidies. Therefore, for smaller places which are unlikely to become bigger places for either economic reasons or rules regarding maximum size (or carrying capacity) certain economic structures are unlikely to develop, and need not be given much analytical consideration.

Role of Location

It is clear that the rate of employment and population growth, as well as measures of welfare such as per capita income, should be significantly influenced by the region's spatial location relative to the metropolitan areas of the country and the existing transportation network, especially the interstate highway system. In like manner, carrying capacity is also dependent on the same locational attributes. This is due to the fact that the close proximity to a major metropolitan area means that the residents in a region can use the services offered by both private and public sectors of that metropolis for many of their demands; the capacity for delivery of these services need not be developed in the smaller region.

An empirical study of the effect of spatial location (see Lewis, 1973) provides evidence that regions in close proximity to metropolitan areas or to the transport systems linking those areas tend to experience higher rates of growth in population, employment, and income as well as having significantly higher income levels. The implications are clear. The development of transportation systems, effectively making a region closer to a given metropolitan area in terms of economic distance, will have growth impacts on that region. The present economic size of the area in relation to its carrying capacity should be evaluated in planning for and evaluating the impacts of new transportation investment.

Interregional Linkages

Focusing on growth in one or a set of regions in a larger, open economy introduces several new dimensions that tend to be omitted in nation-level regional description. Interregional flows of goods, services, capital and residuals tend to be of greater relative importance than do similar flows among nations. Depending on the nature of area delineation, regions often are highly specialized in the production of particular commodities or services. Therefore, a large proportion of domestic output is exported, and, similarly, a large part of domestic consumption and production requirements must be imported. Depending on the regions' saving habits and capital requirements, there will also tend to be substantial interregional capital flows. Hence, the implications for carrying capacity in the absence of import and export quickly emerge. Regional carrying capacities will tend to be very small in relation to larger more diversified areas because of regional specialization in production. Thus, carrying capacity of a region is inversely related to the extent of its specialization in production while for a multiplicity of regions it may be positively related to a variety of regional specializations.

Movements of people among regions present an even more important and more interesting problem. Less than capacity use of human resources has stronger political and economic implications than does unemployment of nonhuman resources. Unfortunately, labor tends to be less mobile than capital, and areas of high unemployment, although typically characterized by out migration, tend to remain such over periods as long as several generations. Economic theory would suggest that differentials in wage and unemployment rates (together with something of an expected income concept) would lead to equilibrating movements of people from low-wage, high-unemployment rate regions. Such movement is generally observed but, at least in recent history, has not succeeded in the elimination of these differentials. There are several possible explanations for this:

1. Individuals may prefer a lower expected income in the home region to the uncertainty, discomforts, and cost of moving to the "advanced area." Essentially, this is an assertion that people are "utility" rather than income maximizers and risk averters rather than risk seekers.
2. The possible concentration of technical progress and scale economics in growing regions may result in the marginal product functions of both labor and capital increasing more than enough to offset increases in the factor supply functions. Such a situation would imply continuing wage and profit differentials among the several regions. The speed of factor movement in reaction to such differentials is critical in the determination of relative factor prices among regions.

Perhaps the point of greatest recent concern in examining interregional linkages is the import and export of residuals and the extent to which significant disassociations between gains and losses are introduced. Both private and public decisions in a small region can easily ignore the full extent of an "externality shed" which can be affected by these decisions. Typically these residuals export problems occur along river systems and air sheds where export of residuals is accomplished at zero cost and their disbenefits are not internalized to the decision process. To the extent that carrying capacities are defined for regions in which residuals generated in production-consumption activities are externalized to that region at no cost, they will be overstated. In essence, such a region internalizes (appropriates) goods and services for local consumption or for export to other regions while it socializes an important portion of the costs of the residuals. Obviously, a full accounting of import and export of residuals is critical to the determination of regional carrying capacity.

REGIONAL GROWTH AND CARRYING CAPACITY

In operationalizing the concept of carrying capacity, it is important to understand the process by which a region grows to or exceeds capacity. Furthermore, regional growth theory is conceptually capable of being linked to models that trace the total impact of economic growth on virtually all aspects of the region, including the effects on demographic characteristics and environmental conditions. Although a regional growth model of general applicability and widespread acceptability has not yet been developed, most regional scientists agree that regional growth depends both on exogenous change in demand for regional outputs and change in the supply and quality of the region's stock of productive factors. In this section, an example of each type of model will be outlined.

Demand Oriented Growth

The export-base model of regional growth is perhaps the most widely used demand oriented model of regional growth. Although it has some rather obvious shortcomings (see Lewis, 1972), it does take explicit account of the importance of forces exogenous to internal growth. Essentially, theory asserts that the region's basic activities (i.e., those which involve the sale of goods and services to consumers whose source of payment comes from extra-regional sources) form the basis for the development of all other basic activities. Exogenous changes in demand for output from a subset of the region's industries, arising from outside the region, are the ultimate source of change in total regional employment with population and labor force adjusting passively. Generally, basic or export activity is concentrated in the manufacturing, extractive, and agricultural sectors.

An example of an export-base type model can be developed in the following way. Total regional employment (E) is identically equal to the sum of employment in the basic (E_b) and nonbasic (E_n) sectors:

$$E = E_b + E_n \tag{1}$$

Basic employment is assumed to be an exogenous variable in that it depends on those extra-regional forces that determine export demand,

$$E_b = E_b^o \tag{2}$$

while nonbasic employment is an increasing function of basic employment,

$$E_n = \alpha_1 + B_1 E_b^o \tag{3}$$

in which $B_1 > 0$. Solving for total employment yields

$$E = \alpha_1 + (1 + B_1) E_b^o \tag{4}$$

in which the derivative of E with respect to E_b^o $(1 + B_1)$ is the total employment multiplier associated with a change in basic employment. B_1 would be interpreted as a nonbasic employment multiplier.

The model is completed by adding an equation in which population (P) in the region is a function of total employment

$$P = \alpha_2 + B_2 E \tag{5}$$

Substituting Equation 4 into Equation 5 yields an equation for population as a function of basic employment only

$$P = \alpha_2 + B_2 \alpha_1 + B_2 (1 + B_1) E_b^o \tag{6}$$

in which $B_2 (1 + B_1)$ would be considered a population-basic employment multiplier.

Any change in the region's employment and population must stem from changes in the one exogenous variable, E_b^o. Strictly speaking, this is not a growth model, although it is commonly referred to as such. In a rather trivial sense, a growth model can be developed by assuming basic employment to be increasing at a constant rate r,

$$E_{bt} = E_b^o = E_b^o e^{rt} \qquad (7)$$

in which t indexes time periods. Under this condition, growth rates for total employment and population will equal that for basic employment. If Equations 4 and 6 were nonlinear, the growth rates would differ among the three variables.

Supply Oriented Regional Growth

The neoclassical model of economic growth provides an excellent tool for identifying sources of growth when they arise on the supply side. Consider a regional economy where only one output (Y) is produced using three factors of production: Capital (K); labor (N); and resources from the natural environment (L), which include land, air, minerals, and water. Thus, the production function can be described as $Y = f(K, N, L, T)$, in which T stands for time and thus dates the period of production. (T) should be interpreted as a proxy for a given "state of the art," and may change from one period of time to another. The output of product (Y) depends upon the quantities of the inputs available for use in the productive process in time period (T) and the level of technological advance being employed in that period.

Each of the factors is assumed to contribute to output. The respective marginal products for capital, labor, and the natural environment are

$$\frac{\partial Y}{\partial K}, \ \frac{\partial Y}{\partial N}, \text{ and } \frac{\partial Y}{\partial L},$$

respectively. Any growth in output between two time periods, say T_0 and T_1, can be expressed in terms of the contributions of the various factors, including technical advance. Thus,

$$\Delta Y = \frac{\partial Y}{\partial K} \Delta K + \frac{\partial Y}{\partial N} \Delta N + \frac{\partial Y}{\partial L} \Delta L + \Delta Y' \tag{8}$$

in which $\Delta Y'$ is the increase in output due solely to technical advance.

Equation 8 can be rewritten as follows:

$$\frac{\Delta Y}{Y} = \frac{K}{Y}\frac{\partial Y}{\partial K}\frac{\Delta K}{K} + \frac{N}{Y}\frac{\partial Y}{\partial N}\frac{\Delta N}{N} + \frac{L}{Y}\frac{\partial Y}{\partial L}\frac{\Delta L}{L} + \frac{\Delta Y'}{Y} \tag{9}$$

or

$$y = \alpha k + \beta n + \epsilon \ell + t \tag{10}$$

in which

$$y = \frac{\Delta Y}{Y}, \ k = \frac{\Delta K}{K}, \ n = \frac{\Delta N}{N}, \ \ell = \frac{\Delta L}{L}, \text{ and } t = \frac{\Delta Y'}{Y} \tag{11}$$

and α, β, and E are respectively the elasticities of production (e. g., $\alpha = \partial Y/\partial K \cdot K/Y$) of the factors capital, labor, and natural environment. Roughly, these elasticities represent the percentage changes in output that result from a one percent change in the inputs, given that the supplies of the other inputs and technical advance are unchanged.

In the context of this study, the neoclassical model is particularly unique in that it would allow the measurement of a change in carrying capacity (e. g., an increase in the private capital stock or the development of a public water resource) to be traced through to its effect on economic growth. Thus, there is an implication that not only does growth influence carrying capacity, but that the converse of this proposition is also true.

SUMMARY

To summarize, regional delineation for analysis of carrying capacity must be based on consideration of the functional elements of three general types of regional space--the ecological space, the economic space, and the policy space. To establish manageable units for analysis within these three regional dimensions, Bahr et al. (1972) suggest the following criteria: (1) The unit should be relatively easy to identify and separate from other units, (2) the units should be capable of being manipulated separately with a minimal effect on other units, (3) the boundaries of the units should remain within, or resemble as close as possible, the less discrete boundaries of the ecosystem so that broad management practices are applicable throughout the unit, and (4) the movement of materials across boundaries can be measured.

SECTION VI

CARRYING CAPACITY IN REGIONAL MODELING

REGIONAL MODELS AND THE ENVIRONMENT

In exploring the relation of carrying capacity to regional resources and regional structure, a key area of interest is that of regional models. There are several ongoing modeling efforts in the area of regional analysis, all of which contain environmental components linked with other regional social and physical components. Within these modeling efforts are reflected various approaches to dealing with the problems of level of spatial detail and the handling of the time (static vs. dynamic) domain. These questions are of importance in attempting to incorporate the notion of carrying capacity into models since its potential for applicability ranges from national or broad regional questions (such as the adequacy of the resource base) to very site specific, spatially detailed questions (such as the impact of a new industry location on water quantity and quality of a particular stream).

The primary thrust in looking at proposed or existing regional models is directed toward the question: To what extent do these models incorporate the carrying capacity concept? This question, of course, relates to the degree to which these models are sensitive to the character of changes that will occur under different alternative management strategies of economic activity and types of resource use, whether such changes are within acceptable limits or tolerances of environmental and social carrying capacity, and how predicted changes in the physical environment relate to the social objectives and values for resource use. This chapter, then, summarizes and compares some of the proposed and existing regional models. For discussion the models are grouped under the following categories: input-output based, simulation, externality, and others.

INPUT-OUTPUT BASED MODELS

Input-Output (I-O) analysis, essentially an examination of the general equilibrium conditions of production, has been widely used to estimate the total impact on all sectors of an economy arising from a change in final demand for the output from any one or perhaps several of those sectors. For applications within the context of a carrying capacity model, I-O analysis can be extended to include the estimation of the residuals associated with any level of production, and more particularly, measurement of the change in residual volumes when output changes.

Given a vector of final demands for each sector's output, F, and a matrix of technical coefficients, A, where each a_{ij} is the value of input from sector i per dollar of output from sector j, the level of sectoral outputs (denoted by a column vector, Q) is given by

$$Q = AQ + F$$

Solving for Q yields

$$Q = (I-A)^{-1}F$$

in which I is an appropriately dimensioned identity matrix. Assuming a typical economy characterized by a high degree of interdependence, the $(I-A)^{-1}$ matrix will tend to have few if any zero components. Thus, a change in any element of F will result in changes in all elements of Q; equivalently, any change in the final demand for one output will result in changes in all outputs.

Now, virtually any production process results not only in outputs but also generates residuals many of which have negative values (e.g., air and water pollution, noise, etc.). Assume there are n industrial sectors and s types of residuals (or pollutants). Construct a matrix, R, dimensioned (s x n) where each element defines the amount of each type of s residuals or pollutant (p_i) discharged per dollar of output (q_j) produced in each sector. That is,

$$r_{ij} = \frac{p_i}{q_j}$$

Now the total level of each pollutant, p_i, which together form the column vector $p_{(s \times 1)}$, is determined by

$$P = R \cdot Q$$

and since $Q = (I-A)^{-1}F$ we can determine residuals as a function of final demand by

$$P = R(I-A)^{-1}F$$

Thus, not only can any change in final demand be traced through the system to determine its effect on output in all sectors, the model can be used to predict the effect of such a change on the levels of all sorts of residuals associated with that change in production. Clearly this type of analysis assumes that technology is constant, at least during the time period necessary for the system to adjust to a new equilibrium; that it is possible to make empirical estimates in the difficult area of the residuals matrix R; and that the input-output relationships are linear. Types of regional environmental models developed from an input-output base are illustrated by the following three examples.

Residuals Management Models

The core of this model proposed by Russell and Spofford (1972) is an interindustry input-output model cast as a linear programming model which optimizes on an "economic efficiency" objective. Figure 13 illustrates the overall model structure. The linear programming interindustry model relates inputs and outputs of various production processes and residuals generated by the production of each product including transformation cost of the residuals. The environmental diffusion model describes the fate of various residuals after their discharge into the environment. Essentially, these are transformation functions operating on residual vectors. Finally, the receptor damage model relates the concentration of residuals in the environment to the resulting damages. While this model is conceptual, further development and applications along the lines of residuals-environmental quality management have been accomplished by Bower and Basta (1973). The modeling

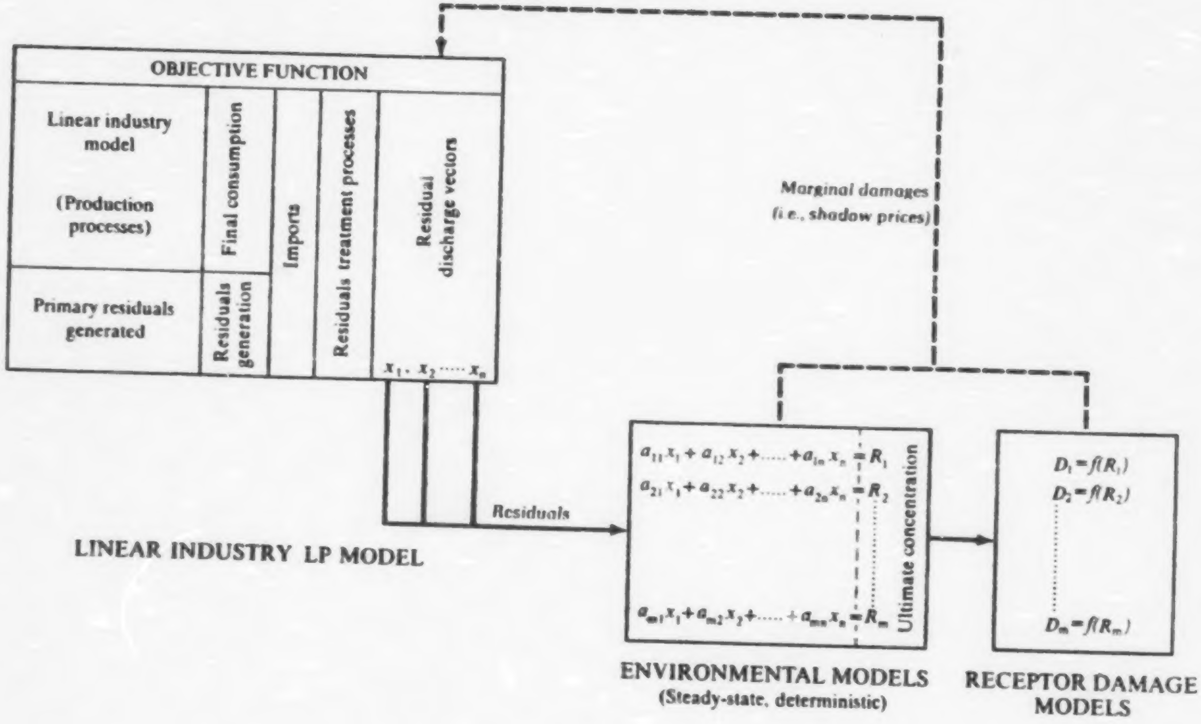

OBJECTIVE FUNCTION
Linear industry model
(Production processes)
Primary residuals generated
Final consumption
Residuals generation
Imports
Residuals treatment processes
Residual discharge vectors
$x_1, x_2 \cdots x_n$
Residuals
LINEAR INDUSTRY LP MODEL
Marginal damages (i.e., shadow prices)
$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n = R_1$
$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n = R_2$
$a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n = R_m$
Ultimate concentration
ENVIRONMENTAL MODELS
(Steady-state, deterministic)
$D_1 = f(R_1)$
$D_2 = f(R_2)$
$D_m = f(R_m)$
RECEPTOR DAMAGE MODELS

Figure 13. Schematic diagram of residuals-environmental quality planning model.

approach examines socio-economic activities, analyzing resource inputs and residuals outputs, the transformation of residuals by environmental processes and the impact of residuals on the receptors. Physical, technological, and institutional strategies for control are examined and analyzed as to their effectiveness. The approach has been applied to a case study in Ljubljana, Yugoslavia.

Ecologic-Economic Analysis Model

This modeling approach (Isard, 1972) places both the economic and the ecologic systems in an input-output framework and combines them through an activity analysis of linkages into a single I-O model for the ecologic-economic system. The key elements are interrelation coefficients between the ecologic and economic activities and their costs. Cost comparison techniques are used in evaluation of alternative activities. Optimization with linear programming (LP) is possible since interrelation coefficients are readily adaptable to an LP format. A case study application of the method is made in the selection of marina site in Plymouth Bay, Massachusetts.

Interindustry Forecasting Model (RFF)

This model developed by Resources for the Future (Herzog and Ridker, 1972) is based on University of Maryland Interindustry Forecasting Model of Almon. Features of the model particularly relevant to carrying capacity (see Figure 14) are projections of both natural resource demand and pollution loadings on the environment, which can be distributed regionally. These are coupled with submodels for water and air which

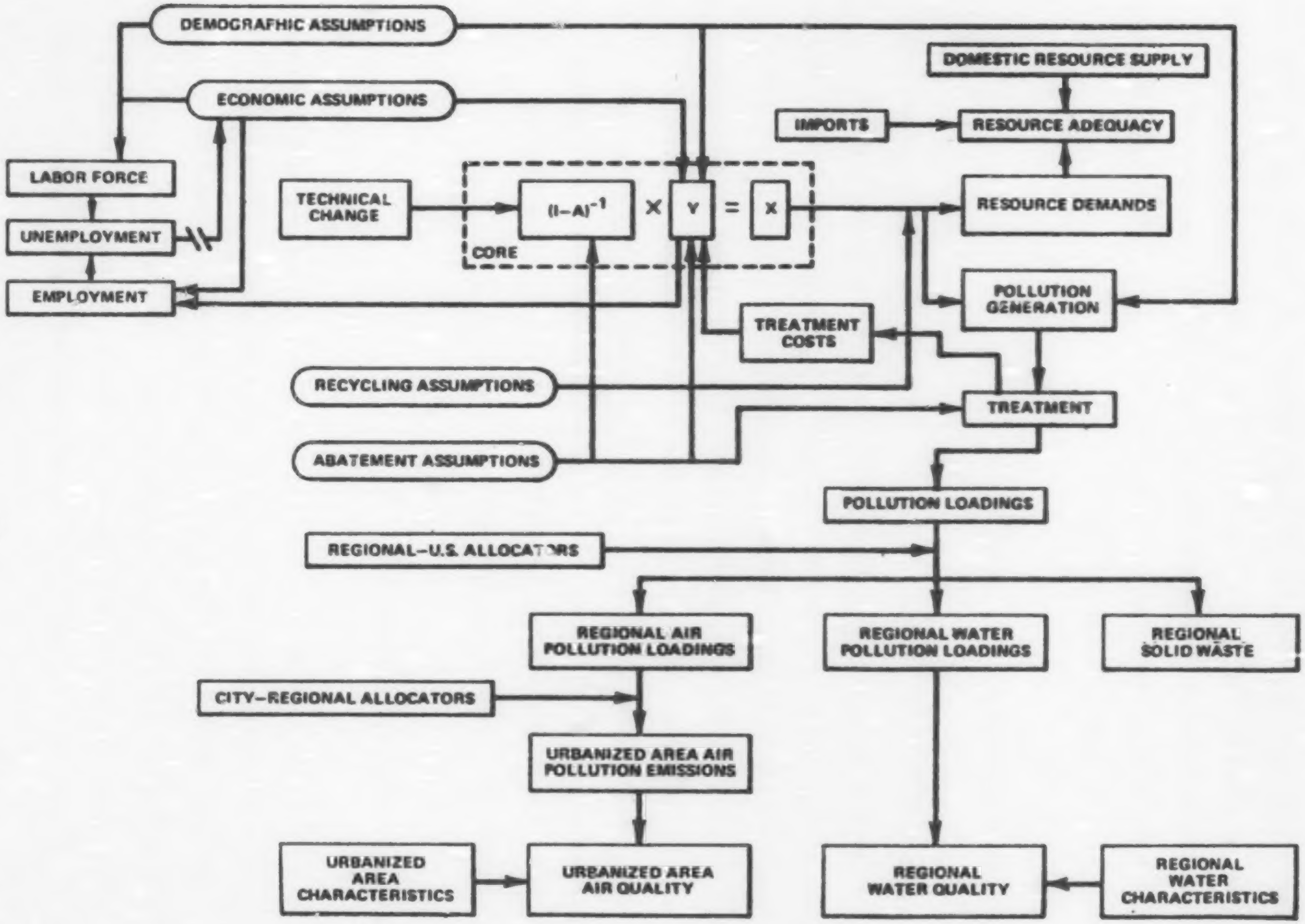

DEMOGRAFHIC ASSUMPTIONS
ECONOMIC ASSUMPTIONS
LABOR FORCE
UNEMPLOYMENT
EMPLOYMENT
TECHNICAL CHANGE
$(I-A)^{-1}$ × Y = X
CORE
DOMESTIC RESOURCE SUPPLY
IMPORTS
RESOURCE ADEQUACY
RESOURCE DEMANDS
POLLUTION GENERATION
TREATMENT COSTS
RECYCLING ASSUMPTIONS
TREATMENT
ABATEMENT ASSUMPTIONS
POLLUTION LOADINGS
REGIONAL–U.S. ALLOCATORS
REGIONAL AIR POLLUTION LOADINGS
REGIONAL WATER POLLUTION LOADINGS
REGIONAL SOLID WASTE
CITY–REGIONAL ALLOCATORS
URBANIZED AREA AIR POLLUTION EMISSIONS
URBANIZED AREA CHARACTERISTICS
URBANIZED AREA AIR QUALITY
REGIONAL WATER QUALITY
REGIONAL WATER CHARACTERISTICS

Figure 14. Schematic outline of RFF model.

can yield water and air quality measures for the future. The suggested model used is to perform various policy simulation to assess future impacts.

I-O Models and Carrying Capacity--A Summary

A common feature built into the I-O type environmental models relevant to the measure of carrying capacity is the ability to assess maximum amounts of residuals discharged by productive activities during, say, the production period that can be tolerated by the regional society. Assume these maximum levels are given by the vector P^*. Now, since

$$P = R \cdot Q$$

the maximum level of output (i.e., the region's carrying capacity of production activities) is defined as that Q, call it Q^*, for which

$$P^* = RQ^*$$

Any Q for which $RQ > P^*$ will cause residuals to exceed the region's minimum environmental standard.

As many residuals are associated with consumption (e.g., driving automobiles) as well as production activities, the analysis must be extended to include consumers and their various consumption activities. As in the production case, this is easily done conceptually, but the empirical measurement problems are particularly difficult.

Another aspect of input-output analysis in relation to carrying capacity is the assessment of the effects of technology and rules changes. Technological developments are occurring constantly, and in recent years more emphasis has been placed on reducing the level of certain residuals associated with given consumption and production activities. Such technological change will result in the reduction of one or more elements of the R matrix of residuals generation coefficients. If all elements of the P vector are held constant (equivalently, if rules concerning the maximum level of various residuals released during a given time period are unchanged) then the decrease in R will imply that the maximum possible level of production Q^* will be greater. Thus, the dimension of carrying capacity as measured by production and employment will be increased.

In an analogous manner, changes in institutional rules will also affect carrying capacity, assuming constant technology. The rules might change in response to changes in the tastes of the region's inhabitants or in response to some crisis. For example, an energy crisis might serve to increase pressure to relax some environmental rules in an effort to accelerate energy production or to increase use of some of the more heavily-polluting fuels. Whatever the reason for the change, the effect on carrying capacity is the same. If the P vector increases (i.e., if one or more elements increase while no others increase) then the region's capacity for production (Q^*) will also increase. A decrease in P, of course, implies a decrease in maximum production. As above, the analysis must be extended to include consumption activities, as changes in technology and rules will have a significant impact on them as well.

SIMULATION MODELS

Modeling is a process of translating physical or social concepts about a particular system into a set of mathematical relationships for the various processes and functions occurring in the real system. Simulation involves the use of a model to carry out experiments designed to reveal certain characteristics of the system. The models should frame concepts and organize knowledge in such a way that questions relating to the modeled system can inductively and logically be answered through a simulation process. Simulation has the following important assets.

1. The model provides a basis for coordinating information and the efforts of interdisciplinary personnel.
2. Complex systems can be studied by modeling their separate parts and by combining their subsystems into the whole.
3. Existing systems can be nondestructively tested, thus proposed modification to a system can be analyzed without perturbing the real system.
4. Many planning and management alternatives and proposals can be studied within a short time period.

All simulation models have three basic properties: Realism, precision, and generality. Realism refers to the degree to which the mathematical statements of the model correspond to the real world concepts they represent. Precision refers to the ability of the model to predict change in the system. Generality has reference to the range of situations where the model is applicable. Since models are imperfect representations of the real world, they are, therefore, subject to varying mixtures of realism, precisions, and generality. Whenever a model is constructed, trade offs must be made between realism and generality, between precision and generality, etc., according to the objectives or intended uses of the model and the data available for model construction.

Validation of simulation models is performed in two steps: Calibration and verification of the model. Data from the prototype system are required in both phases of the verification processes. Model calibration involves adjustment of the model parameters until a "best fit" has been achieved between observed and computed output functions. Model testing is an independent test of results achieved over the calibration phase. During the verification procedure comparisons are made to test the ability of the model to represent the system of the real world. The simulation model does not by itself produce an optimum solution in terms of management objectives. However, the model can produce a rapid evaluation of many possible management alternatives from a very large number of possible choices.

Regional Environmental Systems Model

The Oak Ridge National Laboratories Regional Environmental Systems Model (Craven et al., 1973) is a simulation model composed of four basic submodels, socio-economic, socio-political, land use, and ecological. The flow diagram of Figure 15 shows the interconnection of the various submodels. The model has been developed and operated for the East Tennessee Development District, a 16 county area of 6700 square miles centered around Knoxville.

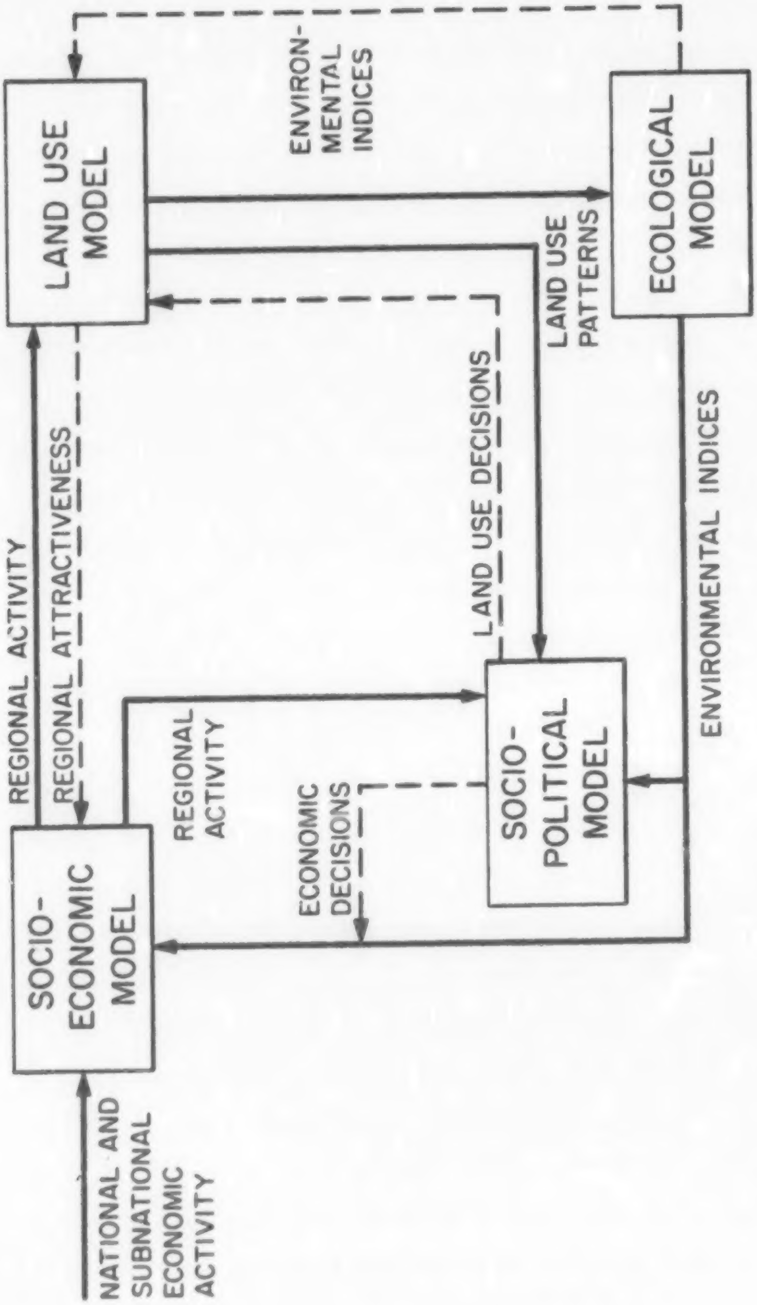

NATIONAL AND SUBNATIONAL ECONOMIC ACTIVITY
SOCIO-ECONOMIC MODEL
REGIONAL ACTIVITY
REGIONAL ATTRACTIVENESS
LAND USE MODEL
REGIONAL ACTIVITY
ECONOMIC DECISIONS
SOCIO-POLITICAL MODEL
LAND USE DECISIONS
LAND USE PATTERNS
ENVIRON-MENTAL INDICES
ECOLOGICAL MODEL
ENVIRONMENTAL INDICES

Figure 15. Regional environmental systems model.

The socio-economic model simulates the dynamics of labor supply (including population) and labor demand for the modeling region. Projection of population and employment is the basic driving force of the model. There are seven components of the socio-economic submodel: Aging, deaths, births, migration, labor force participation, locally oriented employment, and regional export employment. A weighted least square technique is used to fit and test the model's behavioral relationships. The socio-political model is developed to simulate the overall impact of the environment on man, society's perception of this impact, and subsequent management strategies employed by society in response. The model is constructed to display the interactive and dynamic relationships which exist between the governmental units, the general population, and the nonhuman aspects of the regional environment, expressed essentially as an economic model of government revenues and expenditures at various levels in the region. The land use model provides the basis for spatially allocating the regional population and the employment forecasts and then determining related land utilization in the region. Land use indices are used as criteria in the allocation process; a threshold technique is used in locational decisions. Finally, the ecological model simulates the burden placed on the ecosystem by spatially distributed land use activities and the resulting impact on the environmental quality of the system. The ecological model consists of (1) an air and water transport model, (2) aquatic and terrestrial trophic models, and (3) a human activities model. Key elements are quality of air, water, and stream flow, and changes in ecosystem due to changes of those qualities. As the description of the model suggests, transferability and application to other areas is almost a process of starting from scratch because of the many region specific model characteristics.

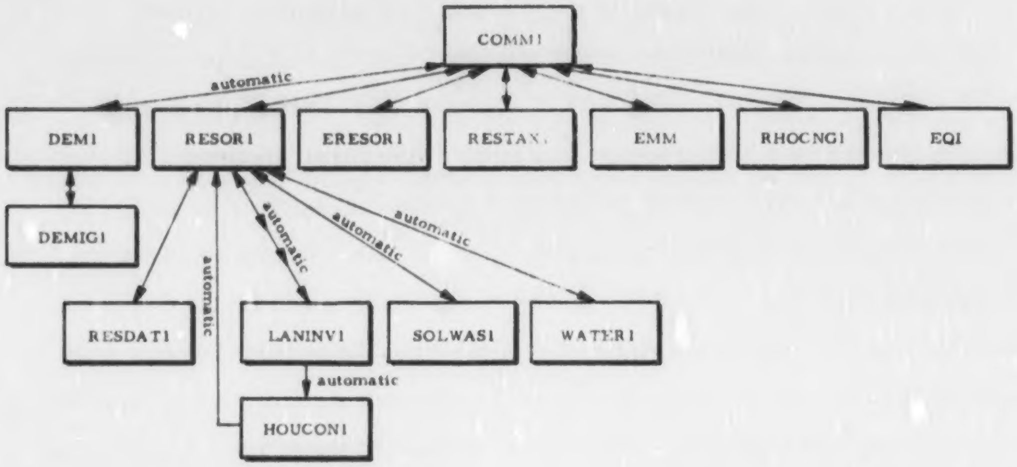
Vancouver Regional Simulation Study

As with the previously mentioned model, this simulation study (Goldberg, Holling, and Kelly, 1971) is also constructed for a specific region. It is interesting to note both the similarities and differences in the component submodels. The demographic model simulates the level of population in the region. Key elements are birth rate, death rate, and net migration rate. An economic model looks at the economic activity of a region resulting from private and public sector spending. Shift-share analysis combined with intersectional flows techniques is used for private sector components. Budget-revenue balancing techniques are used in public sector components. The transportation model simulates the effect of a transportation network on growth patterns of the region. Time-distance is used as the key decision variable. Time-distance is measured along the most convenient arterial road in the area, in case of overland travel. The land utilization model consists of four components: (1) Agriculture--no detail available, (2) forestry--the relation of forest products prices, expected return for water, wildlife, and recreation, (3) recreation--use of central place theory and the theories of retail location as location criteria for parks in the region, and (4) urban land use--location of future demand for land use of various activities types. The health care model determines a quality-of-life index through measures of morbidity, mortality, and disability. Concepts of prevention and care are used in developing this model. The model is presently comprised of four components: (1) Disease generator,

(2) priority streaming, (3) resource allocation for treatment, and (4) estimation of system benefits and feedback of system shortages. The pollution model simulates the transportation and assimilation of pollutants, and their impacts on living systems in the region. There are four components of the model: (1) Air pollution, (2) water pollution, (3) solid waste pollution, and (4) ecological impact. Lastly, the human ecology model, which attempts to devise a means of reflecting the human impact of changes in the character of the urban system, is represented by a proposed activity-subculture description as a working model. The model has been applied in simulating various public policy decisions for the Vancouver region.

Regional Modeling--Piecewise Simulation

This approach to simulation modeling (Watt and Wilson, 1973) is aimed at construction of a more general set of submodels which can be applied to any region specified. Required inputs are basic data for the region for each of the submodels. The 14 subroutines (see Figure 16) in the model are structured so as to allow decision makers to simulate certain policy options and examine their various decision effects. Each subroutine could be considered as a submodel for its designed purpose, but some of the submodels are also used as a component of a more general submodel, for example, the pollution submodel or land use submodel, in the regional simulation. The submodel integration is not carried out, however, probably due to the intention of keeping the simplicity of the overall model to facilitate its use by planners and decision makers. The model has been applied in analyzing the effects of planning policy in some of the urban centers of California.


COMM1
automatic
DEM1
RESOR1
ERESOR1
RESTAX1
EMM
RHOCNG1
EQI
DEMIG1
automatic
automatic
automatic
automatic
RESDAT1
LANINV1
SOLWAS1
WATER1
automatic
HOUCON1

COMM1	The main calling routine. Sets flag for zoning enforcement. User chooses subprograms. Demography subprogram runs automatically.
DEM1	Age-cohort survival demography model gives migration pattern options.
DEMIG1	Performs age specific migration for requested areas.
ERESOR1	Uses per capita electrical energy consumption and natural gas consumption. Computes electrical energy consumption for three categories.
RESTAX1	Uses per capita rates to compute county-wide expenditures for eight categories.
EMM	Optional installation of smog control devices or implementation of rapid transit.
RHOCNG1	Options for building codes regarding maximum height of apartments and housing preferences.
EQ1	Options to separate variables for quality of life and present them in quantity per thousand persons, and number of housing units in unfit condition.
RESDAT1	Option to display data files in tabular form.
LANINV1	Computes land used through time and warns user of remaining amount.
HOUCON1	Markov chain probabilistic model for condition-aging of residential structures.
SOLWAS1	Options for solid waste disposal methods. Computes land requirement for landfill and particulate-to-atmosphere from incineration (if incineration is used).
WATER1	Computes water requirements for multiple, single-unit and duplex dwellings. Computes commercial water use.
RESOR1	Calling routine for resource subprograms. User options for printout.

Figure 16. REGMOD program flow.

Arizona Trade Off Model--ATOM--
Designed for the purpose of providing information relevant to statewide policy issues concerning rates of population and economic growth, changes in composite environmental quality, and distribution of population and economic activity, the ATOM (Myers, 1973) model attempts to portray the trade offs between economic (measured in terms of employment) and environment (measured by the Battelle (Dee et al., 1972) system of environmental quality units). Exogenous to the actual trade off models are (1) a public policy model, (2) an industrial allocation model which produces a ranked list of feasible industries for 6 by 10 mile grid squares based on location requirements (markets, suppliers, transportation) and available resources, and (3) a data base on existing economic, demographic, and environmental characteristics. The evaluation of trade offs is conducted through the use of several linked submodels. These are diagrammed as steps 5 through 14 in Figure 17. First the compatibility of present development with existing or proposed environmental constraints is tested (steps 5 and 6), and then new levels of economic activity and their associated waste generation can be tested against both land use and pollution constraints. If these constraints are violated, several options are available. One is to select different industries that would be more compatible with the environment. A second is to modify the existing level of industrial pollution by the imposition of specific controls that can be met by industry. A third is to revise certain of the environmental constraints. Economic impacts are measured in terms of changes in employment, and environmental impacts in terms of a weighted set of environmental factors. The

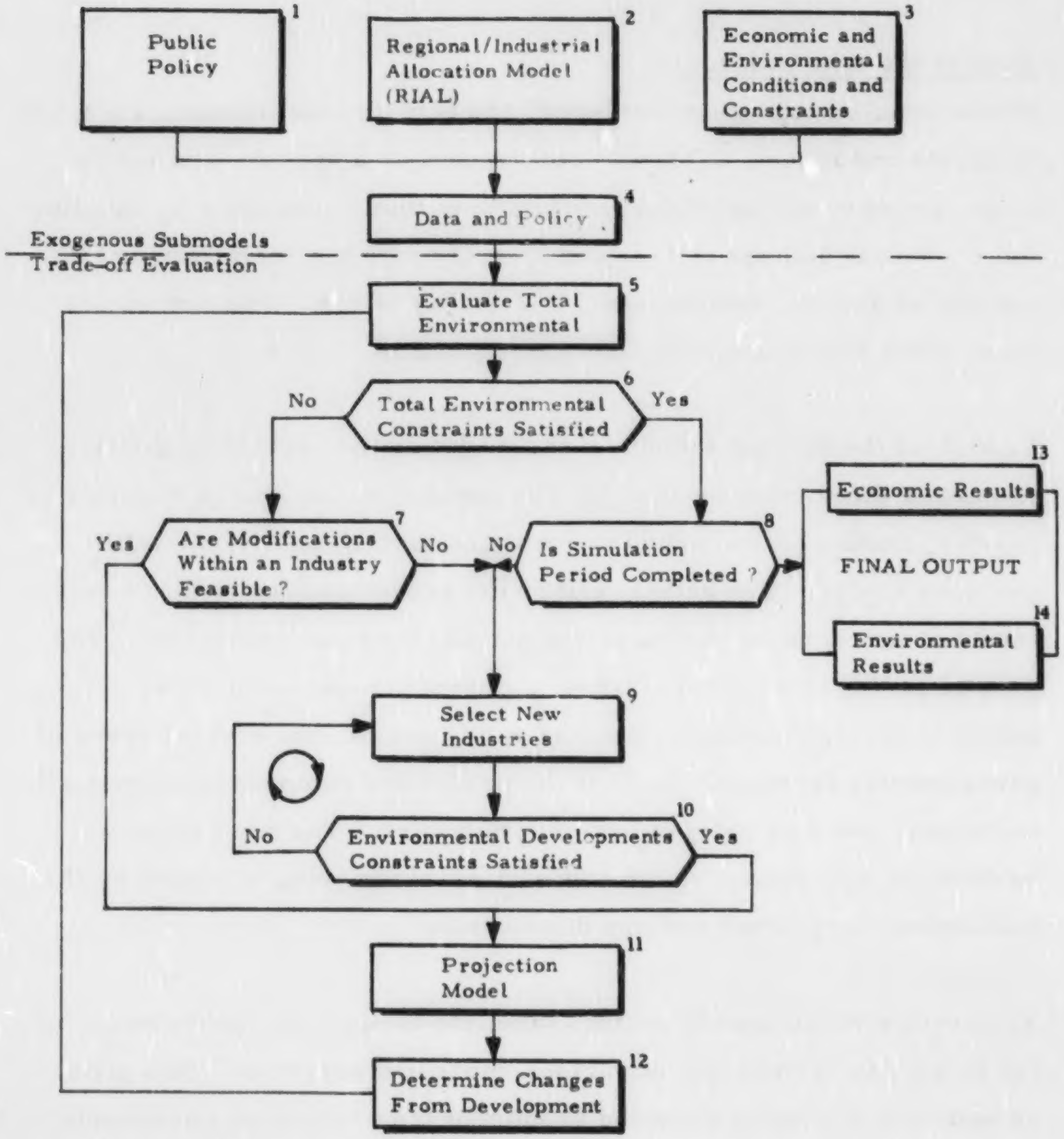

1
Public Policy
2
Regional/Industrial Allocation Model (RIAL)
3
Economic and Environmental Conditions and Constraints
4
Data and Policy
Exogenous Submodels
Trade-off Evaluation
5
Evaluate Total Environmental
6
No
Total Environmental Constraints Satisfied
Yes
13
Economic Results
Yes
Are Modifications Within an Industry Feasible ?
7
No
No
Is Simulation Period Completed ?
8
FINAL OUTPUT
14
Environmental Results
9
Select New Industries
10
No
Environmental Developments Constraints Satisfied
Yes
11
Projection Model
12
Determine Changes From Development

Figure 17. Flow diagram of the Arizona model.

change between the two (or the trade offs) can then be displayed for various policy alternatives. The model is being used by the planning office of the State of Arizona to explore various planning policies.

State of the System Model--

Of the simulation models discussed, the SOS-1 model (House, 1973; and Williams and House, 1973) was constructed as a specific attempt to relate primary and secondary problems of future decisions by coupling the ecological concept of carrying capacity with the social scientists' concept of growth, development, and quality of life. The conceptual form of the SOS-1 model is shown in Figure 18.

In general the driving sectors of the model or the sectors of growth consist of three components: (1) The population, measured in terms of physical needs, (2) the private production sector, and (3) the public services sector. The private and public production sectors are cast in terms of levels of expenditures for maintenance and production. The private sector is subdivided into component categories of heavy industry and light industry, and the public sector into several areas of governmental services. Each of the production components is mutually exclusive, and thus independent growth occurs. The population is partitioned in response to the goods or services being produced by the production components and age distribution.

The results of the growth sectors take into account the expenditures of the system for production of various goods and services. This gives an estimate of outputs provided by each of the production components (production component output in Figure 18). The production component output provides a basis for testing the system limiting factors which

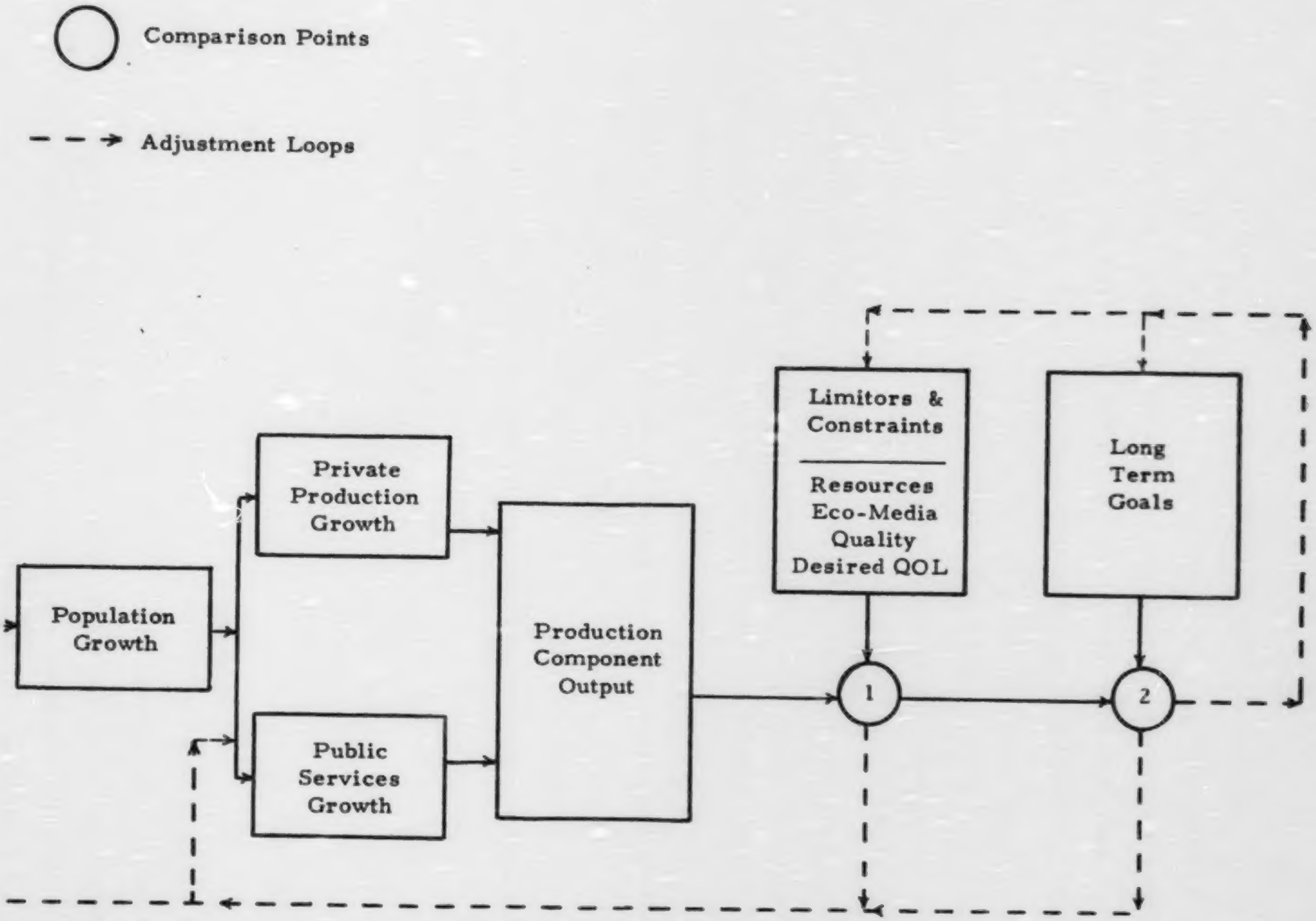

Comparison Points
Adjustment Loops
Population Growth
Private Production Growth
Public Services Growth
Production Component Output
Limitors & Constraints
Resources
Eco-Media Quality
Desired QOL
Long Term Goals
1
2

Figure 18. Conceptual form of state of the system model (Williams and House, 1973).

consist of resource availability, ecosystem support media in terms of treatment requirements, and of societal constraints in the form of demand levels placed on production output components. The comparison is made at the point noted in Figure 19, and if shortages in resource availability or deficient quality in the media (air and water) are apparent, the problem is solved through resource substitution, development of resource reserves, short-term imports, funds redistribution by adjustment of growth, or lowering of social constraints.

The adjustments made within the system are compared with long-term societal goals to determine the affect of the adjustments on future demands for resources and the extent to which system population must reduce its demand levels. The state of the system is described by (1) growth of the population size and demands and the levels of funds available for operating the private and public output sector, (2) the expected levels of goods and services outputs for each component of the public and private sector, and (3) the resource depletion, the quality of the media (air and water), and the quality-of-life measure. If the carrying capacity is exceeded for the resource base or the quality-of-life measure, system adjustments are made.

EXTERNALITY MODELS

Another class of models related to regional carrying capacity are those which consider the externalities that invariably arise as a concomitant of population and employment growth. The existence of external effects generally results in a failure of the market to bring about a socially efficient allocation of resources. In the case of external diseconomies,

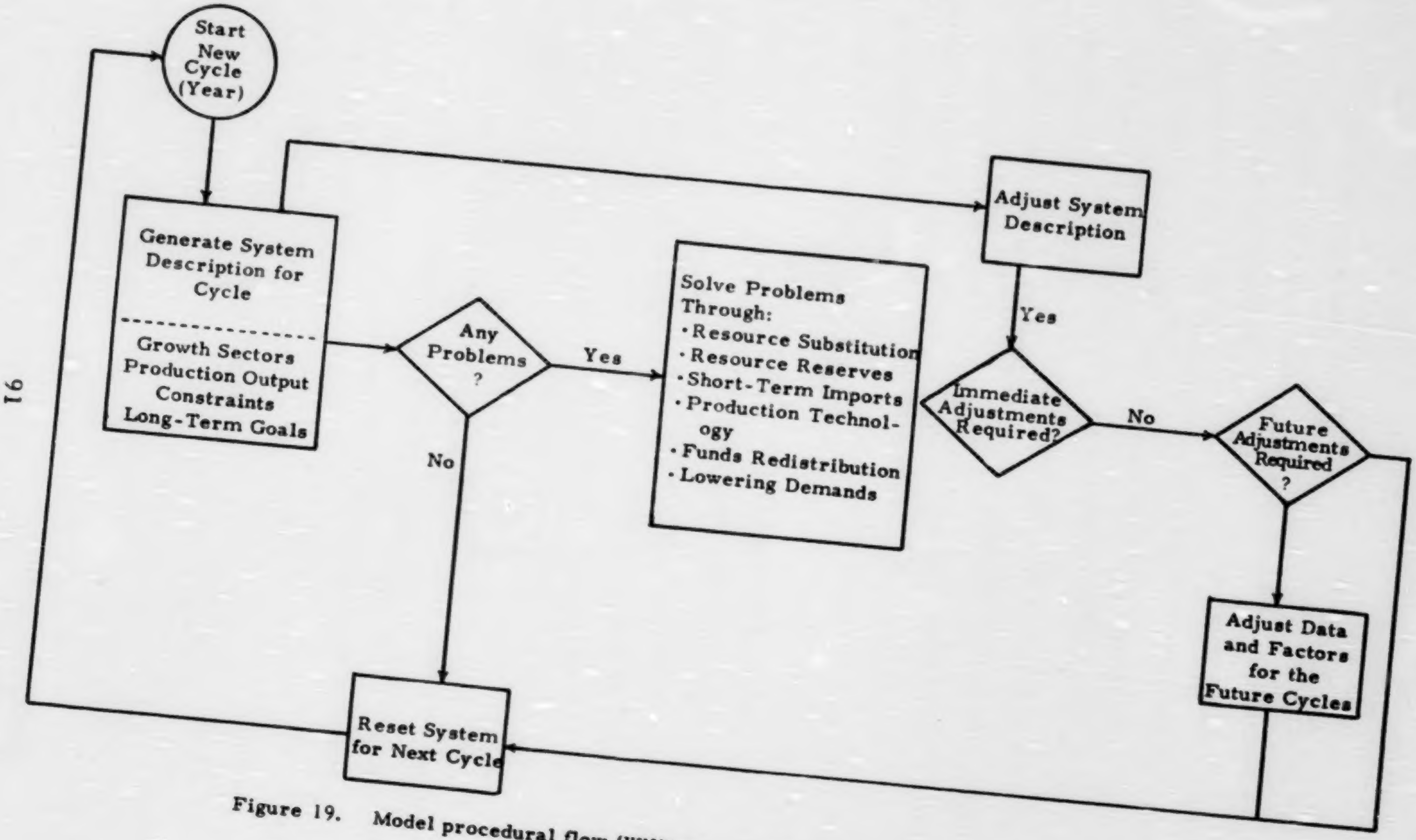

Start
New
Cycle
(Year)
Generate System
Description for
Cycle
Growth Sectors
Production Output
Constraints
Long-Term Goals
Any
Problems
?
Yes
No
Solve Problems
Through:
· Resource Substitution
· Resource Reserves
· Short-Term Imports
· Production Technology
· Funds Redistribution
· Lowering Demands
Adjust System
Description
Yes
Immediate
Adjustments
Required?
No
Future
Adjustments
Required
?
Adjust Data
and Factors
for the
Future Cycles
Reset System
for Next Cycle

Figure 19. Model procedural flow (Williams and House, 1973).

which are easily visible in most urban areas in the form of crime, pollution, and excessive traffic congestion, the result is general dissatisfaction among area residents, but no self-correcting forces are brought into play because individuals are allowed to impose costs on others without making compensatory payments. The end result is usually a call for governmental action to establish rules and laws regulating these externalities. Examples in the pollution field include requirements that emission control devices be put on automobiles, prohibition of open burning of trash, and regulation of fuel use to eliminate or limit the use of highly polluting fuels. On the other hand, all external effects associated with urban or regional growth are not of the negative sort. For example, because of the existence of economies of scale and agglomeration, each new migrant into a growing area tends to make the city, as a productive unit, more efficient and tends to increase both average productivity and average wage levels, thus benefiting all area residents. This phenomenon will be discussed at the end of this section.

External Cost Rate of Increase--

It can be shown that many types of external costs will rise not in proportion to increased population, but more rapidly--perhaps at a rate roughly equal to the square of the increased number of inhabitants (see Baumol, 1967). For example, the dirt, soot, and dust that falls on and in a person's home as a result of air pollution is a function of the number of residents in the area. The relationship might well be proportional, such as

$$s/h = kn$$

in which s/h is sootfall per home, n is number of inhabitants, and k is a constant. The number of homes in the area (h) is probably proportionate to population

$$h = an$$

so that total sootfall (s) on the urban population is given by the number of homes times sootfall per home

$$s = (an)(kn) = akn^2$$

which obviously increases with the square of the population.

A similar example is applicable to transportation. If the average delay (d/n) on an urban expressway is proportional to the number of individuals using it (n)

$$\frac{d}{n} = bn$$

then total delays (d) or man hours lost is equal to average delay times number of users

$$d = (bn) \cdot n = bn^2$$

According to Baumol (1967), this external cost will tend to increase with the square of population.

> The logic of the argument is simple and perhaps rather general; if each inhabitant of an area imposes external costs on every other, and if the magnitude of the costs borne by each individual is roughly proportionate to population size (density), then since these costs are borne by each of the n persons involved, the total external costs will vary not in proportion with n, but with n^2.

Agglomeration Economics--

In contrast to the above analysis of external diseconomies, virtually all empirical evidence indicates that productive efficiency increases with size of city. Such measures as value added per worker, gross regional product per capita, and wage rates tend to increase monotonically with the size of the city. The relationship holds even for the largest cities of the United States. The data suggest that increasing population causes external economies in the form of economies of scale and agglomeration that result in higher wages for all (Alonso, 1971).

Think of the city as an aggregate production unit where output is defined as the value of total product of the urban area for both the public and private sector. Costs will be defined to include not only all private costs (except labor) associated with production in both sectors but the social costs (i.e., negative externalities) associated with urban growth. A set of product and cost curves for the city is shown in Figure 20. The product functions have a positive slope consistent with the empirical data mentioned above while the cost functions are U-shaped to be consistent with both the economic theory of the firm and the models of external costs outlined above. The return to labor (i.e., the total urban population) is the difference between average product and average cost.

For the purpose of defining carrying capacity of a region, four population levels might be relevant: P_1, the minimum efficient city size, below which average cost exceeds average product; P_2, the city size that minimizes average cost; P_3, the population size that maximizes per capita income; and P_4, the population size that maximizes the city's

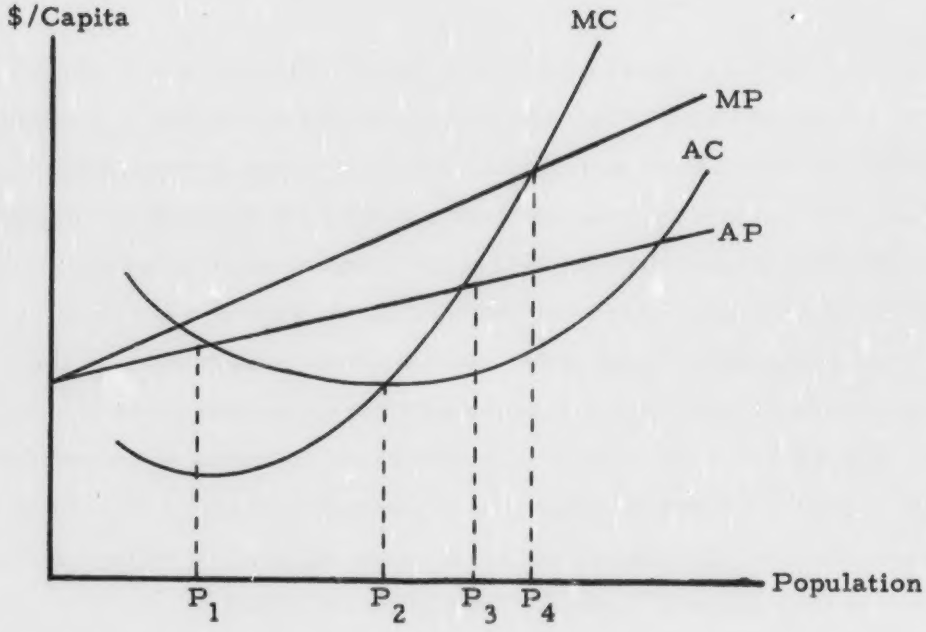


Figure 20. **Urban cost and product curves.**

contribution to national output. Depending on whether a local or national perspective is adopted, population sizes P_3 and P_4 are optimal size cities and might be used as an indicator of the region's economic carrying capacity.

OTHER MODELING APPROACHES

There are, of course, other modeling approaches which are somewhat divergent from the categories already discussed. A few of these are noted as follows:

Economic Pricing for Ecologic-Economic Equilibrium

The basis of the conceptual model development (Koenig and Tummala, 1972) is to identify regulatory and pricing mechanisms that will direct economic activity toward equilibrium states that are ecologically feasible. Ecosystem models are constructed from three basic components: Material transformation, transport, and storage processes. The physical and economic characteristics of the system are obtained by constraining the three "free body" models of the ecosystems by the laws of materials and energy balance as interconnections among the three. A model so constructed is proposed as the basis of computation procedures for analysis of trade offs in the mass-energy and economic characteristics of the alternative ecosystem designs. Conclusion from analysis of the conceptual models developed state that:

> It is shown that in the face of incomplete information on "environmental capacities," it is possible to "hedge" against certain classes of uncertainties through the use of pricing mechanisms.

Environmental "Bookkeeping"

This accounting type of approach (Deitchman, 1972) is offered as an alternative to other types of I-O and simulation models because of the time and difficulty in constructing them. It suggests that if better data were available to describe elements of pollution then better control decisions would be taken. The bookkeeping approach would be used to present decision-making bodies with a number of summary lists including:

1. Consumer products from production processes that also produce wastes (pollution), which in turn enter air, water, and land;
2. The direct costs of producing and distributing those products;
3. The negative effects of those wastes on the sinks; and
4. Measures of quality of life in the presence of those pollution effects.

The proposed approach, according to Deitchman would permit society to make comparisons of the changes that pollution control can bring about in products, effects, direct costs, and measures of quality of life. The results of the social decision processes would then be determined by the value judgments of various parts of society based on those comparisons, and the subsequent social and political dynamics.

Postscript on Regional Modeling

Of the models described, a comparative examination reveals that most of them have elements or features which are related to at least some of the basic definition and the operational elements of a human carrying capacity concept for regional planning. Likewise, they contain assumptions and procedures which do not fit well with either spatial or temporal problems that must be addressed by the concept, or the social-cultural aspects of trade offs among production components that constitute the human environment and aspects of the natural environment.

SECTION VII

A CARRYING CAPACITY PLANNING PROCESS FOR REGIONAL ENVIRONMENTAL MANAGEMENT

INTRODUCTION

The concept of carrying capacity offers a fresh view of problems related to regional organization of man's activity in relation to the environment. Carrying capacity, as defined, is a limit and boundary oriented concept. Relative to resources, it emphasizes that programs and activities must be managed within the capabilities and capacities of natural and human environments to accommodate change and still retain their stability and resilience. It takes note of the net effect of past policy decisions and raises questions about future implications of present policies and actions by asking appropriate questions about the carrying capacity of the environment for future actions and activities.

There is a great need for effective regional and local response to forces of change that will impact significantly on resource utilization and growth of regions of the country. The key question related to carrying capacity is: How can such forces of change, both external and internal to the region, be managed, guided, and controlled so that growth (or decline) in region's activity sectors will occur in an orderly fashion and in such a manner that 1) demands upon the resource base do not exceed supply potentials or assimilative capacities, and 2) levels of production of goods and services, both public and private, for desired quality-of-life levels are maintained?

In examining the capability of a region to sustain existing and proposed activities, consideration must be given to the elements which circumscribe the domains of carrying capacity in a region--the character and extent of the resources, the functions and structures of the region, and the people and institutions. Within this setting, this chapter seeks to articulate a planning process which is based on the concept of carrying capacity as it interacts with the decision-making aspects of regional environmental planning. The description of the process is intended to lay a foundation for interdisciplinary cooperation in regional planning and decision-making processes which affect all aspects of the environment. Within this planning framework, models and analytical techniques can be usefully integrated as tools to predict the response of the environment to proposed changes in a region, and to analyze regional environmental impacts in assessing overall environmental soundness of alternative policies.

SPECIFICATIONS FOR CARRYING CAPACITY-BASED PLANNING PROCESS

Typically the content of information required for planning or policy-making is dictated by the nature of the problem addressed and the questions asked by the decision maker. However, information quality, especially its reliability and credibility, can be significantly affected by the manner in which it is developed and by the spatial and temporal contexts in which it is arrayed. For these reasons it seems appropriate to provide a set of specifications for information provision as a framework for structuring a carrying capacity-based planning and management process.

Spatial Context

Typically decision information boundaries are not coincident in either time or space. Therefore, successful development and implementation of any quantitative approach to information provision and planning must have capability for providing information on capacities of both natural and human environments at various levels of spatial resolution. Planning information is usually developed for a wide range of purposes not all of which can be properly considered within a given "ideal" region. Friedmann (1966, pp. 227-228) states that:

> Although most regional objectives require formulation in terms of a given set of regions, the specific regional relationships calculated from available data can represent any reasonable aggregation of activities and interactions across space. The basic task is to ensure the availability of statistical data on a comparative basis for the smallest area unit which can be advantageously used in spatial analysis.... From these considerations it follows that I am opposed to efforts to impose a quasi-official regionalization upon the United States.... Experience with such efforts has not been satisfactory, despite repeated attempts to discover the one "true" set of regions. Full agreement is never obtained for any set of criteria for regional delimitation; not only will every investigator wish to alter boundaries to suit his ends, but all criteria quickly lapse into obsolescence.

The importance of this specification is emphasized further by Berry (1966, p. 58) in his critique of the suggestion that functional economic areas (FEA's, COG's, and multicounty regions) are more or less "ideal" planning regions. He summarizes as follows:

> First, an understanding of how the economy is organized in geographic space is essential. A regionalization may be useful if it contributes to such an understanding. Some regionalizations are more useful than others; Karl Fox has emphasized what may perhaps be the single most useful regionalization of the country.
>
> Second, to use a set of regions in the planning process one must have goals in mind. On this score Fox's set of functional economic areas (FEA's) has little to offer. One can describe FEA's as of central importance in the economy. Yet it cannot be said that understanding and using them in the planning process necessarily insures that predetermined ends be served. One should not claim too much. It may be that a different set of regions will be necessary to satisfy each set of goals for each different policy.

Noncongruencies in decision information boundaries appear to exist between and within the subsystems of human and natural environments. Certainly the boundaries of watersheds, and air sheds seldom coincide in the natural environment and it is equally unlikely for policy implementation spaces and functionally defined socio-economic units to coincide in the human environment. Thus it is imperative that an aggregative-disaggregative capability be an integral element in the assembly and display (including modeling forms) of planning information. Inherent in this specification is the idea that planning information for small regions must be generated within a consistent macro-regional context. Alternatively, capability should exist to evaluate the cumulative impact of changes initiated outside the macroregion to be traced to small regions.

Temporal Context

The context for information provided by a consideration of alternative time paths is deemed an important characteristic to be included as a specification for carrying capacity decision information. Viewing information in a comparative static reference frame shows only the beginning and the end points of change, but depicts none of the evolutionary processes which lies between them. To do this requires knowledge of the basic behavioral, technical, and definitional relationships among them. Further, it would require knowledge of any changes in these relationships as the system evolved through time. Obviously complete knowledge of this sort is virtually impossible to obtain. However, several abstractions are available at the national and regional levels which provide useful precedents for incorporating this dimension.

An explicit and possibly the least arbitrary means for assessing the time distributions of planning information is to impose alternative exogenous influences in varying sequence and magnitude on pertinent systems (subsystems) in the human and natural environments. If the structure of the system varies predictably or remains constant over time, differences in system outputs can be associated with changes in exogenous forces (inputs). In either case the time path of impacts on a system can be traced by examining a range of "realistic" alternative futures. As in the case of spatial context, the content and resolution of decision information will be dictated by the problem addressed or the question asked by the planner or decision maker.

Implementation Context

The implementation context as specified for a carrying capacity-based planning process is defined in much broader terms than is typical with formal model construction. For example, implementation is deemed to include phases dealing with data assembly, estimation of analytic relationships and integration of suitable models and techniques, and sensitivity and reliability testing. Procedural phases specified in implementation include 1) identification of pertinent systems and appropriate decision boundaries in human and natural environments which will affect or be affected by a contemplated decision or policy, 2) selection of specific spatial units (building blocks) to be used in supplying a data base, 3) assembly and/or estimation of system structure in forms suitable for testing, 4) experimentation and sensitivity testing to determine effectiveness of plans and solutions, and 5) assembly of information outputs into forms suitable for translation to target user groups.

Decision-Maker Role

The interactivity of planners and decision makers (users) is critical as a specification for a carrying capacity process in two ways. First, the process should allow planners and decision makers to fully interact with the analytical models and techniques used as vehicles in the process, and second, the process should stimulate interaction among planners and decision makers themselves. The first point recognizes that the usefulness and application of analytical devices and the decision information they generate is greatly enhanced if provision exists for frequent interaction by the user and researcher throughout the development and implementation stages. It is not unusual, for example, to find complex planning models developed in isolation from the ultimate users of the information. As a result, models fail to address interesting questions at a level of resolution that is helpful to the user. A planning process utilizing carrying capacity-based information must have a high degree of planner-decision maker participation to assure the continuity of data measurement and refinement of analytical techniques.

The second consideration of the decision-makers role in the specification of a carrying capacity-based planning process relates directly to the capability to "weigh" trade offs in capacity changes between desired and prevailing conditions in the human and natural environments. Strong interactive capability of potential information users assures a higher probability of important trade offs being articulated and a lesser degree of polarization among contesting interest groups. These results can be expected to the extent that the decision makers become better informed as a result of their interaction with each other, the planners and public, and their exposure to more complete information concerning the consequences of their actions.

CONCEPTUALIZATION OF A CARRYING CAPACITY PLANNING PROCESS

In general, the goal of planning can be seen as an effort to provide a desired array of "quality-of-life" elements through physical and social design of the human environment. In accomplishing this goal, the planner has traditionally worked within the limits of what is engineeringly and economically feasible and what is socially, politically, and legally acceptable. Usually, the planner has not examined the degree to which physical and functional plans are tied to ecological systems for resource supplies and for residuals assimilation (Cooper and Vlasin). As House (1973) puts it, plans "need to be tested for realism under situations of limited resources and established environmental qualities. That is, they must be related to a regions carrying capacity."

The processes that affect the overall quality of the environment are economic and social for the human environment and evolutionary for the natural environment. The carrying capacity concept, as defined earlier, recognizes that in order to improve the "quality of life" relative to both natural and human environments, the pattern and level of production and consumption activities must be compatible with the capabilities of the natural environment, as well as with social preferences. Recognizing that society is a composite of a wide range of values and expectations, clearly conflicts will exist between consumption associated with desired life styles and feelings for the future conditions of the natural environment. To reconcile the attitudes and expectations for the human environment and the quality and stability of the natural environment, a planning process and analytical mechanisms need to be developed that will provide a way to equitably balance the two.

The carrying capacity planning process described in this section is conceived as a means for resolving conflicts and making trade offs necessary to converge on socially and economically viable and environmentally sound decisions as to future growth and development. As a process, rather than a model, it strongly emphasizes the planner-decision maker-public interaction in formulating plans for managing the natural and human environment.

The process, as presented in Figure 21, logically breaks down into five major component processes for examining changes in human and natural environmental carrying capacities which result from exogenous and endogenous growth forces in a region and the plans to direct them. The carrying capacity planning process, then, serves to integrate and trade off social expectations with ecological and resource capabilities to derive carrying capacities for quality human and natural environments. The following paragraphs briefly set forth the five functional components of the process.

Alternative Futures Description of Regional Driving Forces

The use of alternative future descriptions of regional driving forces as a component process in carrying capacity planning follows naturally from the implications of three of the process specificiations previously elaborated. First, the need to deal with varying regional boundaries for carrying capacity information necessitates a flexible and open approach for dealing with forces of environmental change that are exogenous to the region. These forces cannot be explicitly controlled within the region, yet an understanding of them and their effects internal to the region are of vital importance to regional carrying

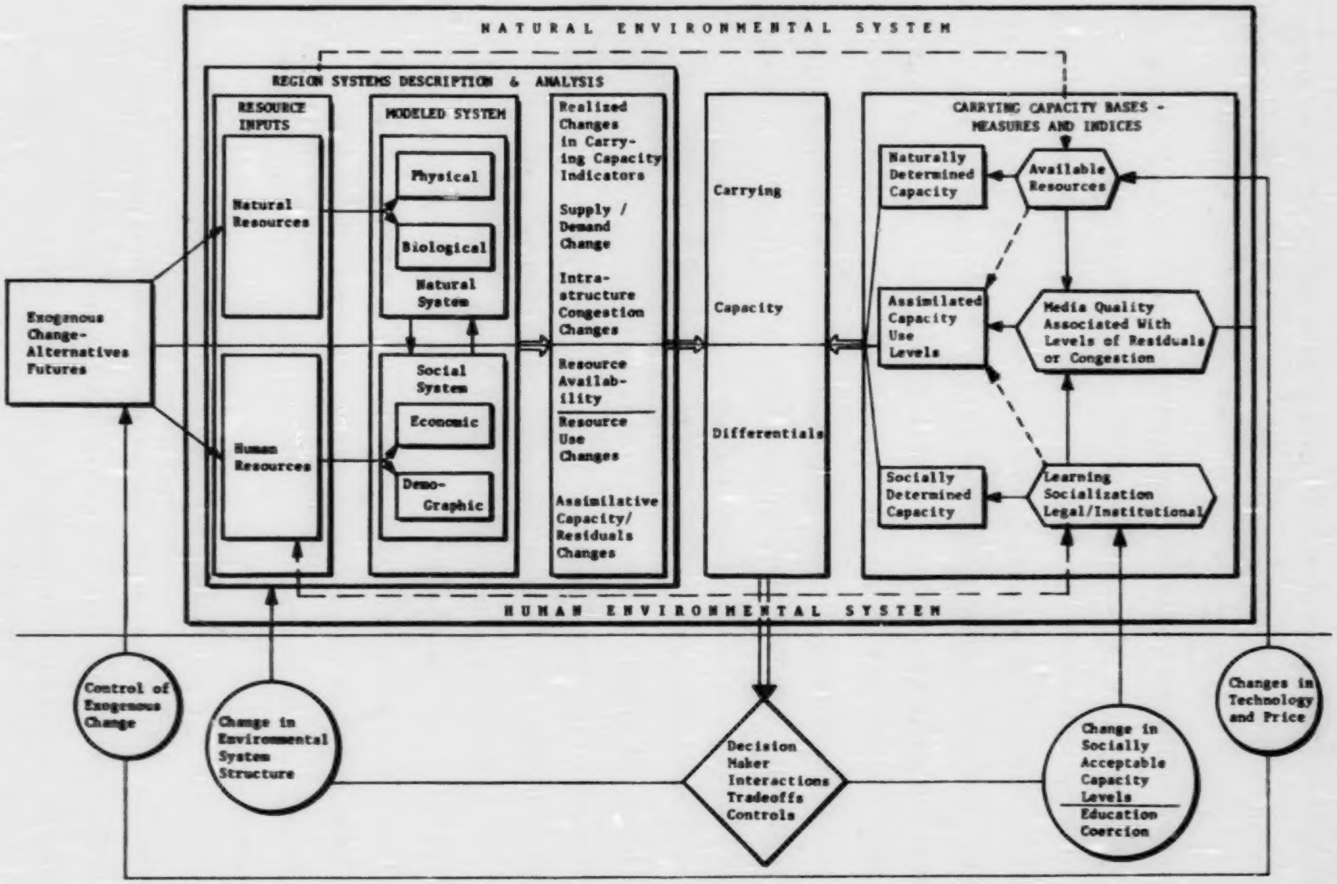

NATURAL ENVIRONMENTAL SYSTEM
REGION SYSTEMS DESCRIPTION & ANALYSIS
RESOURCE INPUTS
Natural Resources
Human Resources
MODELED SYSTEM
Physical
Biological
Natural System
Social System
Economic
Demo-Graphic
Realized Changes in Carrying Capacity Indicators
Supply / Demand Change
Intra-structure Congestion Changes
Resource Availability
Resource Use Changes
Assimilative Capacity/ Residuals Changes
Carrying
Capacity
Differentials
CARRYING CAPACITY BASES - MEASURES AND INDICES
Naturally Determined Capacity
Available Resources
Assimilated Capacity Use Levels
Media Quality Associated With Levels of Residuals or Congestion
Socially Determined Capacity
Learning Socialization Legal/Institutional
HUMAN ENVIRONMENTAL SYSTEM
Exogenous Change-Alternatives Futures
Control of Exogenous Change
Change in Environmental System Structure
Decision Maker Interactions Tradeoffs Controls
Change in Socially Acceptable Capacity Levels
Education Coercion
Changes in Technology and Price

Figure 21. Representative of the carrying capacity planning process.

capacity changes. In this regard attention must be given to events or actions of exogenous change which originate either outside, or at some point within the regional information boundaries.

Second, the need in the temporal dimension to examine transitions to future states directly points to the use of alternative futures constructed of various combinations of possible future events. Alternative futures describe a range of plausible future states affecting the natural and human environment against which the adequacy of plans for the management of regional carrying capacity can be tested. In contrast, projections rely, to greater or lesser extent, upon extrapolation of trends in those areas for which data is available. The danger of such projections is that the future cannot be relied upon to follow past trends. Planning based upon such projections, therefore, may be oriented towards meeting or anticipating conditions that do not come to pass. On the other hand, alternative futures provide descriptions of possible sets of future conditions, and should offer insight into likely levels or magnitudes of "demand" for system outputs. Since shifts in demand are expected in response to such factors as changes in income, population, and leisure time, alternative descriptions of possible future levels of various demand determinants are essential when estimating the probable total magnitudes of change (Bishop, 1973). Hence, emphasis is not placed on producing a forecast, but on identifying the effects of change.

Third, the need for a high degree of planner-decision maker-public interaction in the process is also well served by consideration of alternative futures as regional driving forces. The alternative futures approach places emphasis upon so-called "adaptive planning," in which there is direct and active participation of the decision maker in the planning process. Thus, the alternative futures technique stresses participation over an analysis solely dependent upon modeling techniques, and focuses on the planning process rather than the "plan" as the total product of the planning effort.

Regional Systems Description and Analysis

The determination of changes in regional carrying capacity realized as the result of alternative future driving forces and environmental management plans is the product of the descriptive and analytical capability within this process component. This process function, in effect, operationalizes the specifications dealing with hierarchical levels of spatial detail, temporal dimension of tracing out the time paths of carrying capacity measures and indicators, and implementation which draws on existing data and provides for testability and sensitivity analysis. These specifications provide the essential groundrules for integration of modeling capabilities and techniques for predicting changes in indices of natural and human environmental quality resulting from regional environmental management plans. The perspective of this process component given by Figure 21 is of three general elements: Resource input changes, systems models and analytical techniques, and an output vector of realized changes in carrying capacity indicators.

The system inputs describe the relation of the driving forces to the resource base, and hence the required resource data. This includes physical resources and inputs to production, media qualities and assimilative capacities, and relevant socio-economic and demographic information.

The systems models and analytical techniques are an integration and linking of working models and tools to analyze resource allocation and capacities, and the environmental impacts of alternative futures driving forces. A comprehensive picture of the analytical relationships and levels of spatial resolution in determining carrying capacity changes is presented in Figure 22. The diagram recognizes four primary levels of modeling and analysis representing progressively higher degrees of spatial resolution, linking the resource input changes from the driving forces to the changes in carrying capacity indicators. Beginning at a broad regional level, economic and demographic models describe production, consumption, and resource exchange within the region in terms of required natural resource, raw material, and social infrastructure inputs, on the one hand, and the outputs of goods and services and residuals, on the other. These four classes of resource state changes, associated respectively with resource base, social system, economic system, and resource media and ecological system, are operated on by a series of "models" representing higher degrees of spatial and temporal resolution. These models and analytical tools include materials transformation models, distributive spatial and temporal models, and finally, human and natural environmental impact models.

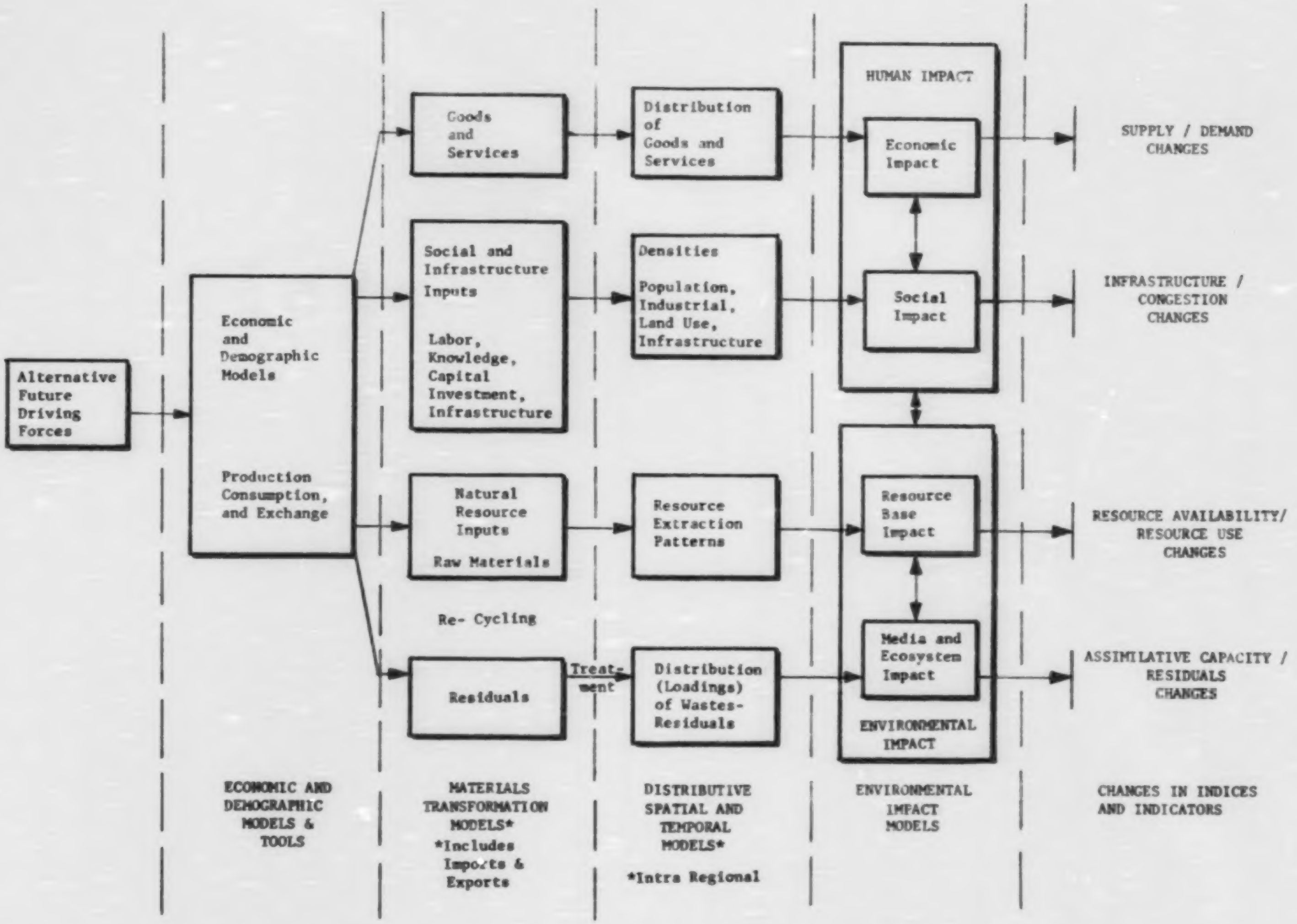

Alternative Future Driving Forces
Economic and Demographic Models
Production Consumption, and Exchange
Goods and Services
Social and Infrastructure Inputs
Labor, Knowledge, Capital Investment, Infrastructure
Natural Resource Inputs
Raw Materials
Re- Cycling
Residuals
Treat- ment
Distribution of Goods and Services
Densities
Population, Industrial, Land Use, Infrastructure
Resource Extraction Patterns
Distribution (Loadings) of Wastes- Residuals
HUMAN IMPACT
Economic Impact
Social Impact
Resource Base Impact
Media and Ecosystem Impact
ENVIRONMENTAL IMPACT
SUPPLY / DEMAND CHANGES
INFRASTRUCTURE / CONGESTION CHANGES
RESOURCE AVAILABILITY/ RESOURCE USE CHANGES
ASSIMILATIVE CAPACITY / RESIDUALS CHANGES
ECONOMIC AND DEMOGRAPHIC MODELS & TOOLS
MATERIALS TRANSFORMATION MODELS*
*Includes Imports & Exports
DISTRIBUTIVE SPATIAL AND TEMPORAL MODELS*
*Intra Regional
ENVIRONMENTAL IMPACT MODELS
CHANGES IN INDICES AND INDICATORS

Figure 22. Relation of modeling and analytical techniques for carrying capacity.

The outputs from these successive levels of modeling and analysis are changes in the capacity measures or indicators for four general classes of indices, viz., supply and demand, infrastructure and congestion, resource use and resource availability, and waste loading and assimilative capacity. This vector of capacity changes summarizes and displays the implications of future actions and their higher order effects in light of limited resources and environmental qualities, the changes or shifts in infrastructure and land use (congestion), and the distribution of goods and services that would result from activities associated with the alternative futures. These output measures of resource capacity, then, provide the basis for examining the effects of carrying capacity constraints and limits that will impinge upon, affect or regulate events and activities associated with alternative futures. For example:

1. Environmental standards, controls, regulations,
2. Resource limits and capacities (rate of use, depletion of stocks, assimilative capabilities, resource recovery and recycling, discovery of new resources and improved efficiency in production through technology, and substitutability of resources), and
3. Social and institutional factors (demands for goods and services, attitudes toward conservation and environmental protection, etc.).

Carrying Capacity Bases: Measures and Indices

This process component deals with the problem of measuring the outputs of productive activity and utilizing these measures to assess the carrying capacity of a region. As Figure 22 indicates, production outputs may be divided into two classes: (1) Goods and services and (2) wastes and residuals. Measurements for the former (social indicators) may be used to gage the relative change in human productive and social processes. Measurements for the latter (environmental indicators) allow managers and decision makers to determine how productive activity affects the quality, assimilative and future productive capacity of the receiving environment.

To describe considerations in measurement of change in human and environmental capacities, several definitions will be helpful. The term "indicator" is used to represent any measurement of conditional states or changes in states in human and natural environments (e.g., amount of BOD or SO_2, number of cars recalled annually, number of reported crimes). Several indicators may be integrated into a single index for more complex conditions or components (e.g., air quality, consumer price index). Indices at an intermediate level of aggregation may, in turn, be integrated into still more general indices (e.g., GNP, quality of life, environmental quality). The term "index," then, is used to represent a measurement of some environmental or social component for which there is more than one indicator. It should be noted that such aggregated components cannot be measured directly. Through the use of an appropriate indexing function and measurements for its indicators, however, these components can be measured indirectly.

Indicator/index research has been undertaken as a means of organizing technical and particular information into more generally understandable carrying capacity of a region. As Figure 22 indicates, production outputs may be divided into two classes: (1) Goods and services and (2) wastes and residuals. Measurements for the former (social indicators) may be used to gage the relative change in human productive and social processes. Measurements for the latter (environmental indicators) allow managers and decision makers to determine how productive activity affects the quality, assimilative and future productive capacity of the receiving environment.

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Indicator/index research has been undertaken as a means of organizing technical and particular information into more generally understandable and practically useful information. The Third Annual Report of the Council on Environmental Quality (CEQ) characterized this concern:

> One of the most effective ways to communicate information on environmental trends to policymakers and the general public is with indices. An index is a quantitative measure which aggregates and summarizes the available data on a particular problem... The nature and complexity of the index will depend on the subject matter and the purpose the index is to serve.
>
> Information on the environment can be presented to the public in a format which lies anywhere along a continuum ranging from the raw data at one extreme to a single index number for the whole environment at the other... The use of a limited number of environmental indices, by aggregating and summarizing available data, could illustrate major trends and highlight the existence of significant environmental conditions.

The work of CEQ may also be characterized as an effort to develop means for measuring progress towards environmental quality standards and as a way for assessing the success of Federal, State, local, and private environmental protection activities.

In general, the work on indicators has been conducted under two general conceptual perspectives. One perspective views indicators as a means of assessing progress towards the attainment of social (or environmental) goals, or, alternatively, of quality of life (or environmental quality) norms or standards. Some contend that this stresses ideal conditions and is heavily value laden. Thus, a variation on this general approach views indicators as a means of measuring progress towards the achievement of social and environmental minimums, i.e., the basic survival needs of human and nonhuman populations (Corning, 1971).

The second conceptual perspective considers social and environmental indicators in a systems framework. Land (1971), for example, views social indicators as statistics that "(1) are components in a model of a social system, (2) can be collected at various points in time and accumulated into a time-series, and (3) can be aggregated or disaggregated to levels appropriate to the specifications of the model." He suggests the generation of social system models of such social conditions as poverty, health, leisure, and education. More ambitiously, Fox (1969) sought to develop procedures for quantifying inputs and outputs in social systems, developing a gross social product, and identifying what variables might need to be considered in such an analysis.

Efforts to utilize indices in a systems framework have met with some success in micro-economic and environmental modeling efforts. In fact, it appears that an amalgum of these two perspectives would be most useful in developing indices for use in a carrying capacity-based planning process. Typically the very large number of state conditions in human and natural environments become more or less incomprehensive to both laymen and decision makers. This confusion may be attributable to an over abundance of seemingly unrelated state conditions and the apparent lack of contextual bases for these conditions. As suggested above, indexing is specifically designed to provide a realistic condensation (indices) of various state conditions. Additionally, the contextual problem can be reduced by linking indices to pertinent systems and data bases which maximize their information context. In some instances, the appropriate index/system linkages can be suitably depicted by formal modeling approaches, while in others more heuristic analyses and approaches may be required. In any case, an analysis of regional carrying capacity will require a systems approach and utilize indices to provide information concerning capacity changes in the human and natural environments. The formal identification of these index/system relationships is depicted in Figure 21.

Note that this figure is divided into three components. On the left is a schematic representation of index/system relationships labeled region systems description and analysis. This component reflects the essential linkages between "realized" carrying capacity indices and the structural system(s), resources, and exogenous driving forces. An essential distinguishing feature concerning the information output of this component is that it depicts realized changes in carrying capacity, and therefore is analytic and descriptive in nature. On the right is a second set of index/system relationships labeled carrying capacity bases. This process component reflects the essential linkages between desired or "ideal" indices of carrying capacity and elements of the human and natural environment. Thus it provides a symmetric variant of the regional systems description differing from it because of the normative character of the indices. Technically, the two sets of indices, descriptive and normative, could be identical in which case the center component carrying capacity differential would not exist. However, this is not expected to be the case. Rather, this center component focuses attention on shortfalls, excesses and trade offs which typically exist between descriptive and normative indices of carrying capacities. It is this focus which provides operational objectives for a carrying capacity-based planning process and facilitates identification of management (control) strategies and their intervention points among the components of the process.

Thus if carrying capacity indices of the sort described above could be developed such that qualitative changes in human and natural environments could be monitored in a carrying capacity planning process, a basis would exist for evaluating the performance of regional systems in terms of pertinent indices of carrying capacity changes and their divergence from "ideal" magnitudes for the same indices.

A considerable effort has been directed toward the development of descriptive and normative indices of both the human and natural environments. Since such indices represent possible measures for carrying capacity changes the following paragraphs briefly summarize and provide examples of some of the current work in the area.

Natural Environment Indices--

In the natural environment, for example, the CEQ reports that "progress in developing indices for air pollution is more advanced than in any other environmental area." Under CEQ contracts, the Mitre Corporation has developed two indices for assessing trends in air quality: The Mitre Air Quality Index (MAQI) and the Extreme Value Index (EVI). Another index--the Oak Ridge Air Quality Index (ORAQI)--has also been developed by the Oak Ridge National Laboratory.

Other indices are being or have been developed for other areas of environmental concern, notably water pollution, pesticides, toxic substances, land use, and wildlife. For each of these areas, CEQ has identified what it assumes are the critical indicators. Once satisfactory indices can be developed for the above areas of environmental concern, intermediate level indices will presumably be aggregated into an overall environmental quality index. Such an EQ index for the nation has been developed by the National Wildlife Federation, and on a regional scale, the County of San Diego plans to develop an EQ index and has made substantial progress in developing requisite subindices.

The state of the art in the development of particular environmental quality indices and the establishment of monitoring systems to provide requisite data for the calculation of these indices appear to warrant the conclusion that it appears feasible to incorporate such environmental quality performance criteria into a carrying capacity-based planning process.

Human Environment Indices--
Numerous similar efforts have been directed toward the development of indices relating the condition of human environments for a variety of region types. Essentially these are designed to evaluate the performance of social programs and institutions in providing for the needs, desires, and aspirations of various publics and of assessing how index levels effect and are affected by other variables in the supporting system(s). A first step in exploring this problem involves identifying carrying capacity indices in the human environment. Such a list might be comprehensive and complete, or it might be partial and representative, depending on the type of question or problem under consideration.

The Technical Committee (1971) effort to develop the "Strawman" is a good example of the comprehensive approach. In this study, an interdisciplinary task force identified nine general social goals descriptive of the human environment (collective security, environmental security, individual security, economic opportunity, cultural and community opportunity, aesthetic opportunity, recreational opportunity, individual freedom and variety, and educational opportunity), disaggregated these goals into several tiers of subgoals, and identified social indicators under each lowest-level subgoal. This hierarchical array is intended to approximate what is meant by the phrase "social well-being." To illustrate, the tentative disaggregation of the economic opportunity goal is provided in Table 3. Taking a less comprehensive indexing approach to evaluate the outputs of productive activity, a "community attractiveness profile" might be developed using only a few critical indices.

The "state of the art" in indexing techniques appears to be sufficiently advanced to warrant their incorporation in an analysis that would relate productive activity (public and private) to quality levels in both the human and natural environments. Indices can serve the purposes of examining how environments are affected by productive activity and how, in turn, the relaxation or upgrading of these norms affect productive capability through time.

Carrying Capacity Differentials and Adjustments

The tests of usefulness for a carrying capacity-based planning process are found in the capability of such a process to 1) articulate differentials (short-falls, excesses, trade offs) between "desired" (normative)

Table 3. DISAGGREGATION OF THE "ECONOMIC OPPORTUNITY" SOCIAL GOAL INTO SOCIAL INDICATORS (TECHCOM)

A. Present standard of living
   1. Median per capita income
   2. Prices of goods and services
      --Cost of Living Index
      --Consumer Price Index
   3. Quality of goods and services
      --Repair costs per capita as a percent of purchase price
      --Cars recalled annually as percent of total
   4. Selection of goods and services
      --Percent change in the number of new patents issued
      --Retail employees per capita
      --Retail per capita sales receipts
   5. Leisure time
      --Average weekly working hours
      --Per capita receipts of amusement and recreation service establishments
      --Per capita attendance at State Parks
      --Per capita sales of hunting and fishing licenses
   6. Stability
      --Percent growth rate of per capita income
      --Inflation rate
      --Unemployment rate
      --Business failures as a percent of the total number of businesses

B. Future standard of living
   1. Employment potential
      --Employment growth rate (percent)
      --Unemployment rate (percent)
      --Net migration as a percent of total population
      --Median education level (years)
      --Median income growth rate (percent)
   2. Savings and investment potential
      --Economic growth rate (percent)
      --Population growth rate (percent)
   3. Retirement potential
      --Social insurance contributions per capita
      --Private insurance contributions per capita

C. Equality of economic opportunity
      --Gini coefficient for income distribution by income class
      --Median education for ethnic groups
      --Employment rate for ethnic groups
      --Ratio of female unemployment rate to male unemployment rate

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The items prefixed by dashes (--) are social indicators.

and "realized" or descriptive (empirically determined) changes in carrying capacity indices, and to 2) identify intervention points for initiation of various control or management strategies. Obviously a recognition of divergence as between "real" and "desired" carrying capacities, or changes in them, is basic to the identification of appropriate and effective management strategies. "Desired" levels of supply/demand satisfaction must necessarily be weighed against "realized" changes in congestion, resource availability and waste assimilative capabilities. Likewise, "desired" indices reflecting important features of the material environment or changes in them, could be arrayed against "realized" indices of economic and social well-being.

Although this approach suggested a certain degree of polarization between interest groups if they align themselves in terms of potential trade offs among different indices of carrying capacity, the interactivity usually associated with an articulation and weighing of these trade offs should enhance communication and the understanding of the consequences of their respective decisions. This interactivity among decision maker, planner and researcher in all phases of the planning process will influence the mix and focus of control strategies because commonality of interests can more easily be identified, thus reducing the necessity of employing coercive management strategies.

As depicted in Figure 21, decision-maker interactions are considered the key element in implementing alternative carrying capacity management strategies in response to recognized differentials between pertinent indices of "realized" and "ideal" carrying capacity. Three basic strategies emerge, falling roughly into the categories of attitudinal, institutional and informational. Obviously these are not mutually exclusive, and depending upon the situation being addressed may be most effectively applied in concert. Four intervention points have been identified in Figure 21 for the application of these strategies.

The first is directed toward changing or controlling the magnitude, timing or location of exogenous driving forces. For example, a recognized differential or short-fall between "realized" and "ideal" indices for air quality may be effectively controlled by imposing restrictions on neighboring regions whose particulate wastes are currently being exported into adjoining regions. Alternatively, export taxes could be employed to discourage production of those export commodities which contribute significant quantities of particulate matter to the regions air sheds. Such measures fit roughly into the institutional category of management strategy. Institutional measures may be implemented either by mutual consent or by probationary-coercive means, depending primarily upon the extent to which decision information identifies interregional commonality of interest. Commonality, of course, is not always present, but the availability of information facilitates its emergence and thus serves to diminish the likelihood of interregional conflicts.

The second and third intervention points are in the areas of system structure, denoted as region systems description and carrying capacity bases in Figure 21. In these cases, carrying capacity differentials are addressed by introducing measures designed to change the basic structure of the system such that input/output conversion rates are altered in desired directions. Such a strategy is basically informational in character and seeks to introduce improved technologies, or more efficient management, in areas of the indices for which a carrying capacity differential exists. In some instances, a similar modification in structure may be introduced only by using institutional strategies in combination with informational forms to induce or coerce the adoption of technologies which would not otherwise be used. Common examples are provided by legislated standards on air and water effluents and the various residuals tax and subsidy schemes. The latter are highly flexible means for changing relative prices and hence input/output relationships in production systems which in turn govern carrying capacity indices.

Finally, and perhaps most importantly is the intervention point in the area of soil tastes and tolerances. The strategies assignable to this area are basically attitudinal in character but would typically include use of some elements of institutional and informational forms. Importance is assigned to this control means because of its obvious presence in establishing "ideal" indices of carrying capacity. Socialization and educational processes, as well as material well-being influence socially determined carrying capacities, especially in relatively affluent societies in which subsistence needs are easily filled.

Ideal carrying capacity indices are most susceptable to change and are perhaps the most volatile of control measures for eliminating carrying capacity differentials in regions and societies where there is extensive mass communication. This does not necessarily mean that carrying capacity differentials based on "ideal" limits can be readily changed by propagandizing the human population, but rather that given time and sufficient exposure, those capacities which involve tastes and preferences of higher order, can be and typically are conditioned by information.

THE CARRYING CAPACITY PLANNING PROCESS AND ENVIRONMENTAL MANAGEMENT

In developing environmental management strategies for the urban region, planners and decision makers must continually assess the social and environmental implications of various proposals. Recognizing and establishing the limits or capacities of regional activity support systems along the lines of the carrying capacity planning process described in this chapter could provide decision makers with a workable approach to assessing the natural and human viability of proposals.

Indices have begun to develop as a means of providing a working knowledge of environmental quality, and of charting trends and changes in quality levels. The development of carrying capacity concepts can extend the usefulness of these indicators beyond just showing trends in to the realm of making comparative evaluations of environmental quality dimensions in terms of ranges and limits of acceptable levels, and the impact of various regional growth policies.

Regional environmental management which incorporates a carrying capacity planning process can thus be used to examine the character of changes that will occur under different levels of activity and types of resource use, whether such changes are within acceptable limits of environmental and social carrying capacity, and how predicted changes in the physical environment relate to the social objectives and values for resource use.

SECTION VIII

APPLYING CARRYING CAPACITY IN A LOCAL URBAN SETTING

CARRYING CAPACITY IN PLANNING ACTIVITIES

This chapter will trace some of the implications of the carrying capacity concept for planning at the local level. Viewed against the planning perspective sketched in the last chapter, it seems fair to say that planning at the city or county level can accommodate carrying capacity considerations if it involves: 1) Identifying those events and decisions (driving forces)--present and future, local and remote--that will likely result in significant local changes, 2) inventorying existing conditions to establish baseline data for the area's natural and human resources, 3) estimating how existing conditions will be modified by the driving forces, 4) formulating alternative policies and programs for dealing with such change, 5) estimating the trade offs that would be involved among the alternatives as a basis for deciding on best courses of action, and 6) implementing these decisions. Using analyses from previous chapters and various examples, the remainder of this chapter will explain how the planning framework outlined above can accommodate carrying capacity ideas and analyses.

Identification of Driving Forces

One of the local planner's most important tasks is to identify the events and decisions that will have serious and extensive impacts in the area of his planning jurisdiction. These events and decisions may have already occurred, are occurring now, or are likely to occur in the future. They might occur locally, or even elsewhere in the state or nation. Examples of such driving forces are the location of basic and important service industries, federal revenue sharing, the location of interstate highways and other transportation facilities, changes in population and demographic make-up, policies affecting water and energy supplies, the installation of federal facilities, state and federal supreme court decisions affecting methods of financing public services, and so on.

Acknowledging that such driving forces can occur in various combinations and in various ways, it is useful to describe alternative futures for the planning area. One future might describe a maximal growth situation; another a minimal growth situation. The most probable future--the one derived from describing the most probable mix of the most probable driving forces--would usually describe a future intermediate between these two extremes. A useful methodology for identifying driving forces and organizing them under alternative futures has been developed by Kane (1972).

The identification of driving forces necessitates full and effective communication among representatives from industry, government, and other segments of the local community as well as communication between local leaders and officials in state and federal government. Once the planner has characterized in alternative future scenarios the forces that will likely result in extensive changes in his city or county, he is faced with the tasks of developing an analytical framework for analyzing and evaluating the effects of such change and channeling it in directions that will protect and benefit the community at large.

Inventory of Existing Resources

In order to examine how driving forces will affect changes in a community's natural and human resource base, it is necessary, first, to survey and inventory existing conditions and to determine the state of the community's existing resources. For accomplishing this inventory, a resource classification such as that presented in Chapter II is suggested:

Ambient resources:	air, water, open space, quiet and noise zones, sunlight exposure
Spatial resources:	underground space, available and transitional surface space, airways space
Infrastructure and distributive resources:	transportation, water and water distribution, wastewater collection, energy (electricity and gas) distribution, communications
Ecological resources:	green plants, nongreen plants, animals

Socio-cultural resources:	educational and cultural facilities, health services, security services (fire, police), recreation services, housing stocks
Economic resources:	raw materials for production inputs, capital, labor
Amenity resources:	seashores, scenic areas, contiguous natural areas (mountains, deserts, lakes), open space

Table 4 indicates some of the kinds of questions that need to be asked and how the inventory might be organized for renewable or flow resources. Table 5 provides a similar organization for nonrenewable or stock resources. A more complete inventory would and should involve assessing the qualitative states of existing resources.

Assessment of Changes in the Resource Base Under Alternative Futures

The last chapter discussed methodologies and analytical procedures that might be employed in identifying or predicting the effects of certain driving forces. There are various ways of organizing and classifying such effects, of course. One mode of organization might involve considering how the entries in a resource inventory, such as Tables 4 and 5, would change. Additionally, the planner might want to aggregate changed entries or parameters in the inventory table to assess changes in such higher order indices as "air quality," "unemployment rate," "crime rate," and even "quality of life" and "environmental quality." (See the previous chapter for a more complete discussion of how the

Table 4. RENEWABLE OR FLOW RESOURCES

Resource	Unit Cost of Use or Procurement	Regional Net Annual Use of Procurement Cost	Total Dollar Amounts		Distribution		Regional Ownership (%)			
								Public		
			Imported	Exported	Time	Space	Private	Fed.	State	Local
Ambient air water open space quiet and noise zones sunlight exposure										
Transformation and Distributive transportation water and water distribution wastewater collection energy distribution communications etc.										
Ecological green plants animals etc.										
Socio-Cultural educational facilities health services security services etc.										
Economic capital labor etc.			all columns should be estimated for each resource classification and quality type							

Table 5. NONRENEWABLE OR STOCK RESOURCES

Resource	Unit Cost of Use or Procurement	Regional Net Annual Use of Procurement Cost	Total Dollar Amounts		Estimated Life Potential	Estimated Annual Depletion Rate	Distribution		Regional Ownership (%)			
			Imported	Export			Time	Space	Private	Public		
										Fed.	State	Local
Spatial underground airways transitional etc.												
Economic raw materials for production etc.												
Amenity seashores scenic areas open space etc.				all columns should be estimated for each resource classification and quality type								

construction of indices might be used to measure various kinds of social, economic, and environmental change.)

Ultimately, the way impact information is or should be organized depends on the use to which this information is used for policy- and decision-making purposes. In this context, four general areas of human-oriented carrying capacity have been identified: 1) The capacity of the resource base to supply production demands, 2) the capacity of production to supply the demands for goods and services, 3) the capacity of infrastructure to distribute goods and services and the materials used in the production of goods and services efficiently, and 4) the capacity of the natural environment to assimilate wastes and residuals resulting from production and consumption. These dimensions or areas of carrying capacity are, of course, highly interactive. Attempts to assign carrying capacity limits or ranges must be based on a recognition that deficient capacity in one area affects carrying capacity in the others. If a planner has the staff and facilities or can call upon the requisite expertise, he will be able to analyze the carrying capacity of systems along the lines suggested in the last chapter. Often, however, limited budgets and manpower will necessitate a less systematic and comprehensive analysis of carrying capacity conditions and limits. The following problems and case studies are offered as examples of how carrying capacity analyses might be conducted when planning resources are limited. Each of these examples identify driving forces and suggest the kinds of effects that need to be taken into consideration.

Atlantic Coast Brown-Outs--

Recently, heavy demands for electrical energy on the Northeastern Atlantic Seaboard have exceeded the generating capacity of the system. This stress on the system beyond its capability to produce or supply electrical energy has resulted in some brown-outs and threats of others. Viewing this as a carrying capacity problem, a number of questions in regional planning arise as to what should be appropriate responses: Should generating capacity be expanded, and if so, how much? What would be the effect of an expansion on other supportive resources, e.g., fuel for steam electric plants, effects of waste heat disposal on water bodies, effects of particulate matter in the air? What effect would expansion have on growth in the region? What policies could be implemented to reduce energy demand by consumers? What would be the impact of such policies?

Water Importation to Salt Lake Valley--

Water supplies available for municipal, industrial, and agricultural use in the Salt Lake Valley are limited to presently developed surface and groundwater sources. The availability of these present supplies imposes a limit on the levels of water uses that can be sustained. Part of the Central Utah Water Development Project proposes to import additional water supplies into the Salt Lake Valley. The accomplishment of such a proposal will effectively increase the carrying capacity of available water supplies to support activities. To do so, however, raises a number of other carrying capacity related issues: What will be the impact of increased activity on the carrying capacity of other resources, e.g., wastewater disposal and assimilative capacities, air pollution, availability of land and land quality? What impetus will there be for additional growth, and with what impact on other supportive resources and infrastructure?

Urban Center Expansion--

The Ogden Valley, situated 5 miles east of Ogden, Utah, is basically a rural agricultural valley of roughly 50 square miles with a total population of about one thousand residing in three small communities. It is reached via a winding two-lane road through the short and scenic Ogden Canyon. The canyon itself is an important recreation resource offering excellent fishing and camping by the river which flows from the valley watershed and the Pine View Reservoir. The Ogden Valley offers extensive recreation opportunities for residents of the urbanized Ogden and Salt Lake City regions. The reservoir is a major water-based recreational area offering swimming, boating, and fishing. In addition, golfing, picnicking, and camping facilities have been developed in the valley, and two major ski areas on the mountain slopes serve the winter recreationists. Upland and mountain wildlife species abound in the valley and the surrounding mountain forest areas. Presently, there are a number of proposals for large developments in the area ranging from vacation resorts to condominiums to lower density summer home developments to housing tract developments for bedroom communities for the urban areas. The Highway Department is considering plans for major improvements in access to the valley. In the face of the mounting pressure for development and the serious and irreversible environmental demage which could result, a comprehensive analysis of the carrying capacity of the Ogden Valley is greatly needed. Some of the carrying capacity related issues and questions are: What is the capacity of the reservoir and the river downstream to maintain the natural water quality levels and continue to support existing ecosystems? What is the capacity of soil to resist erosion from intensive recreation or development use? What is the capacity of the valley to provide infrastructure for development--water supplies, wastewater disposal, solid waste disposal areas? What capacity constraints are imposed by the existing transportation system? What will be the effects of the proposed high speed access? What will be the impact of air quality conditions with increased traffic along with housing and commerical developments? What plant and animal species will be displaced, and what will be the capacity of ecological systems to absorb changes from development? What is the capacity of the valley to serve as an open space and recreation resource?

Recreation Development in Watersheds--
The canyons immediately above Salt Lake City are being subjected to intense pressure for development. These canyon watersheds supply most of the water needs for the Salt Lake Valley. They also provide an outstanding recreational resource for winter skiing and summer mountain outings and vacations. Large resorts have already developed in the canyons to serve recreation interests with many new resort hotel and private summer home developments proposed. Again, questions relating growth and carrying capacity arise: What is the capacity of the fragile watershed ecosystems to support various intensities of development and recreation use? What is the capacity of air and water resource systems to absorb the pollutants from these developments? Can a transportation system of adequate capacity be constructed without complete disruption of the canyon ecosystem? What user-capacity

can the recreational areas accommodate and still provide satisfactory recreational experiences?

The foregoing case examples underscore the highly interactive character of the four dimensions of carrying capacity. Again, the four general areas in which the carrying capacity of a populated region might fail are: (1) Supply/demand for resources in the production of goods and services, (2) supply/demand for goods and services by consumers, (3) efficiency of distributive resources/distribution requirements, and (4) assimilative capacity of the receiving environment/levels of wastes and residuals generated from production and consumption. Five additional examples are provided below to clarify further some of the issues involved in (3) and (4). The first three cases deal with (3); the latter two deal with (4). In these more specific cases, it should be noted the carrying capacity dimensions are still highly interactive although a more narrow examination of the carrying capacity aspects of the problem is undertaken for illustrative purposes.

Urban Freeway Congestion--
Rush hour freeway congestion of urban regions may be cited as an example of carrying capacity in terms of an infrastructure or service delivery system. The freeway has a given capacity relative to the maximum volume of flow in a given period of time. When vehicles overload the system, volume drops off as traffic congestion creates stoppages and delays which tend to reduce flows to zero. In terms of the regional capacity to provide transportation services, some of the issues are: How much freeway capacity can be provided without infringing on quality levels of other air, land, and water related

resources? How will expansion of freeway transportation capacity affect the expansion of other urban activities with their subsequent effects? What would be the impact of measures to limit freeway usage at capacity levels for the present system?

Treatment Plant Capacity--

In counties surrounding urban areas (Washington, D.C., for example), continued expansion of residential and commercial development into the urban fringe has placed heavy burdens on existing wastewater treatment and disposal facilities already operating at capacity. In such instances, no additional sewer hookups can be allowed without overloading the system and causing pollutants to enter nearby streams and rivers. Here, again, the capacity of existing infrastructure along with enforcement of standards on effluent discharges acts as a carrying capacity constraint on the region. In this situation some relevant questions are: What will be the effects on growth of providing additional waste disposal capacity? How will removal of this capacity constraint affect other aspects of environmental quality in the region such as open space, pressure on recreation and other cultural resources, and delivery systems for other social services? What will be the impact of a moratorium on additional building permits or maintaining current waste disposal capacities?

Recreational Resources--

Recreation resources of the nation have been under mounting pressure over the past several years. Of particular concern are areas of unique natural and scenic beauty such as the national parks. In Yosemite for example, the large number of visitors traveling through the park in vehicles caused serious congestion, air quality problems, and a reduction in the overall quality of experience for the park visitors. Some of the carrying capacity questions which perhaps were considered in adopting new rules for park visitations were: What number of visitors could the park accommodate and still provide a desired level of quality experience for the recreator? Can number of visitors be increased or must they be reduced? What programs should be implemented to effect appropriate changes in numbers? How should the number of visitors be accommodated without endangering the resource itself?

Wastewater Disposal and Water Pollution--
Pollution of rivers and lakes by the disposal of heavy waste loads in these receiving waters has become a common problem across the country. Where the ability of the water resource to assimilate these waste loads has been exceeded, there has been attendant destruction of the aquatic ecosystem, as well as decreases in the potential for water use in other activities. In two cases in the Northwest, polluted waters were upgraded to near their natural quality levels. Lake Washington in Seattle was being heavily polluted by wastes from residential and commercial development which had grown up around it over the years. However, reduction of the pollution load through comprehensive wastewater management has allowed the lake to regenerate to quality levels that will again permit swimming and recreational use. The Willamette River in Oregon, highly polluted by pulp mill and other industrial wastes, has also been cleaned up to the point where anadromous fish runs are again being reestablished. The capacity of water to assimilate wastes and residuals depends on the enforcement of water quality standards. Some of the carrying capacity

questions with respect to determining these standards are: What other uses are intended for waters which will be affected by setting of certain standards? What economic, environmental and social costs and trade offs are involved in maintaining high quality levels in a water body as opposed merely to using it as a waste carrier?

Air Pollution and Emissions Control--
Excesses in the use of air sheds to assimilate emissions has also become a pervasive problem. The ability of the air to assimilate such emissions is, of course, dependent on the meteorological conditions prevailing over a given time. The loading function, however, is related to the activities and processes going on within the region as well as to the enforcement of quality standards. Controls to maintain those standards, applied to the activities or sources of emissions, bring up some of the following carrying capacity questions: How will emission controls to maintain air quality levels affect other activity levels, such as transportation and industrial production? What will be the regional impact of reducing levels of these activities to satisfy emission standards? How will the substitution of other activities or technological controls affect carrying capacity? What are the social, economic, and environmental costs of maintaining specified standards?

In summary, virtually every urban center is faced with problems of accommodating some degree of future development. In managing the environment for quality regional growth, questions related to the carrying capacity of environmental resources lie at the heart of the problem. These short examples provide only a broad glimpse of the issues which overlay a myriad of technical questions about the ability of resources to accommodate growth without precipitous declines in environmental quality of the particular area and other contiguous areas which draw upon it for basic resource support. The carrying capacity concept implies viewing the regional environment as a support system for numerous, interdependent and competing activities and systems, and determining the limiting conditions and capabilities of the regional environment to absorb, withstand, support or sustain these activities without downward trends or unacceptable changes in quality levels.

Formulation of Alternatives

Once driving forces have been identified and the range of their impacts estimated, the planner is faced with the task of formulating alternative ways of coping with change and channeling it in safe and beneficial directions. In doing so, he should ask the kinds of carrying capacity questions that were asked in the series of examples in the last section. Alternatives that would threaten to seriously diminish the carrying capacity of key support systems in the community should, of course, be ruled out of any further consideration.

Evaluation of Trade Offs

The next step is that of evaluating proposals and competing management alternatives. The merit of any community or society, or of any institution, policy, or program within that society, must be judged finally by its effectiveness in providing a good life for its members. It is, of course, a difficult and challenging task to define "the good life" and cognates such as "quality of life." Equally difficult is the task of measuring the progress that programs and policies might be making toward the establishment and maintenance of "quality life." These problems were discussed in Chapter V and will not be reexamined. Suffice it to say here that there are a multiplicity of elements making up "quality life" and that any policy or program will involve promoting or safeguarding certain of these elements while sacrificing or jeopardizing others. Every action involves value trade offs. The evaluation stage in planning involves identifying the range of trade offs involved in and among alternative courses of action, determining the relative importance of values involved in these trade offs, and choosing the trade off mix that most nearly satisfies one's decision principle (e.g., maximizing positive values or minimizing negative values).

Before turning to a fuller treatment of implementation problems, one further comment needs to be made about carrying capacity as a value to be reckoned with in the evaluation process. When production demands exceed requisite resource inputs; or the demand for essential goods and services cannot be met by a community's productive capability; or congestion and inefficiency in a community's infrastructure and distributive resources result in frequent and recurring blockages, stops, and delays; or the atmosphere and terrestrial and aquatic environments cannot assimilate wastes and quality levels in these media cannot be maintained at safe and tolerable levels--when carrying capacities such as these are exceeded, society as a whole suffers. Zones of safe carrying capacity are essential to the efficient functioning of a community and to the achievement of personal and social values. In this fundamental way, carrying capacity is an important extrinsic value and one the planner cannot afford to ignore.

Implementation

Once strategies for managing change in society have been evaluated and selected, effective means must be found for implementing these strategies in an established and on-going institutional and social setting. This section will address the problem of implementation by focusing on three critical areas in which carrying capacity controls might be exercised: Population, economic activity, and land use.

Human Population--

The human population variable has been considered in many carrying capacity studies as perhaps the most important variable. If the human population is too high then a portion of this population should be decreased; if the population is too low then population increase can be allowed or stimulated. Of the three factors important for population change--fertility, mortality, and migration--only migration effects any very rapid changes in population. There are important differences in birth and death rates, of course, but these are more determined by differences in the age level of specific populations than by anything else. Older populations have high death rates and young populations have high overall birth rates. Differences in fertility were once considerable, but the differences have become much smaller in the most recent decades. Also, there appears to be very little difference among areas in the United States in overall mortality. Therefore, it is migration that has the most startling effects on the population of an area. Lee et al. (1971), for example, found that more than 70 percent of the persons entering adulthood during the 1950 to 1960 decade left some mid-western rural counties. They found instances where the median age in a county rose ten years in just a single decade because of the out migration of the younger population.

With this great potential for the change in the population of an area, it would appear desirable on the surface to devise some means to effect population changes very quickly in a given region. In reality, however, population change is not particularly amenable to manipulation by the political sector of the nation. In fact, our traditional means of handling population change has been to maintain a laissez-faire attitude by government. The federal courts have not allowed states or their subdivisions to control the movement of persons within the United States. This constitutional doctrine was tested early in the history of the Union when in 1865 the Legislature of the State of Nevada enacted a statute that levied a tax of one dollar upon every person leaving the state. No doubt the legislators of Nevada wished to discourage out migration. In 1868 the case of Crandall vs. Nevada reached the Supreme Court of the United States and the Nevada statute was declared unconstitutional (6 Wall. 35-1968). Mr. Justice Miller in writing the majority opinion for the court indicated that every citizen in the United States has the right to travel to the seat of government, unrestricted, or to otherwise have free access to ports, land office or other offices operated by the national government.

Further elaboration on the right of the free movement of persons within the United States is found in the case of Edwards vs. California which came before the Supreme Court of the United States in 1941 (314 United States 160-1941). This case came about because the Legislature of the State of California had, during the great depression, passed a law which prohibited the transporting of indigent persons into the state. Mr. Justice Byrnes in delivering the opinion of the court used very strong language to strike down this California statute. He pointed out that although the states did have constitutionally mandated police power (the power to protect the health, welfare, and morals of the community) this did not mean that there were no boundaries to a state's legislative activity in this area. He indicated that no state could gain a momentary respite from the pressure of events by the simple expedient of shutting its gates to the outside world. Generally speaking, it appears that any attempt by a state or its subdivision to overtly limit migration would be held unconstitutional by the Supreme Court of the United States.

This is not to say that the national government, or even state governments, has been without policies that affected migration in the past. Policies exist even if they are not well articulated. An example of a population policy can be found in the law that permitted homesteading in the American West. In this case the national government essentially gave 160 acres of land to any person who would live on that land for a specified period of time. With this law in effect the vast spaces of the West filled up between the period of the Civil War and the turn of the century. Another example of a population policy can be seen in the National Housing Act of 1937 and its subsequent amendments. This act established the Federal Housing Administration system of mortgage insurance thereby allowing the middle class of the United States to construct new housing and to move in such great numbers into the suburbs after World War II. A third example is the interstate highway system which consists of super highways going away from or into cities, depending on your viewpoint, which have allowed Americans to live long distances away from their work and still commute by automobile in comfortable fashion to and from their place of work. These latter two policies have contributed to the depopulation of our major American cities and the building of a whole new urban form--the urban sprawl.

Economic Development--
Economic development as discussed here is viewed very narrowly as the investment of capital or movement of wealth into an area. Migration appears to be closely related to economic development, and under many circumstances it is directly induced by economic development. Migration is clearly influenced by the business cycle, with higher immigration rates seen into areas with a prosperous economy and lower immigration, or even out migration seen in the less prosperous areas. This explains the high influx of the southern rural poor into the more affluent northern metropolitan counties in the period 1945 to 1970 (Bowles et al., 1969; Gallaway, 1960). Much of this migration, of course, was tied to the disappearance of employment opportunities in the rural areas as agriculture was rapidly mechanized during this period. An example of this can be seen in the data shown in Table 6. As Utah's per capita income fell relative to the average United States per capita income in the 1960's, considerable out migration occurred. Also, note that as the relative income of Utah residents rose at the beginning of the decade and in the early 1970's, in migration was experienced. In the decade 1960-1970, the state population increased by 18.9 percent, but this was entirely due to the excess of births over deaths because the net loss due to migration was 1.2 percent (Hiibner, 1973).

Table 6. UTAH PER CAPITA INCOME AND NET MIGRATION 1960-1972

Year	Utah as a Percent of U. S. (per capita income)[a]	Estimated Net Migration (percent)[b]
1960	89.1	9.8
1961	90.2	15.4
1962	91.4	1.8
1963	90.2	-3.1
1964	87.8	-13.9
1965	85.9	-3.5
1966	83.6	2.3
1967	82.8	-6.1
1968	81.9	-6.4
1969	80.3	1.1
1970	81.9	0.3
1971	82.8	8.9
1972	83.0	12.7

[a] Utah Economic and Business Review, Vol. 33, No. 10 (Oct., 1973).

[b] Utah Economic and Business Review, Vol. 33, No. 5 (May, 1973).

Land Use and Land Use Planning--

The concept of land use planning is relatively new in the United States. Historically, the individual property owner was free to use his property as he wished, but this has changed drastically since 1928 when zoning was sanctioned as within the permissible "police power" of the states (Euclid vs. Ambler Realty Company, 272 United States 365). Now almost every unit of government regulates, in some way, the use of land and has the means to implement land use plans. This is not to say that land use planning or its means of enforcement, zoning laws, are always wisely used or not abused. Large tracts of land surrounding American cities have been "planned" for use as estates with two or more acre lots containing only single family dwellings, and as lots of this size cost in excess of $10,000 per lot, it has become impossible for a low income family to move into these areas. Most likely the worst excesses of this type of "planning" will soon be gone, but they appear quite bothersome at the present time.

Several positive benefits have been achieved through land use planning, such as protection from housing and industrial encroachment on areas important to water recharge, wildlife production, high value agriculture production, or historical preservation. Population density can also be controlled. Through effective land use planning and zoning, industrial pollution of air sheds and watersheds can be prevented by planning for industrial developments in areas where the least harm may be done. The location of urban infrastructure (utilities, roads, and public facilities) can be programmed in advance so that inconvenience to the newly developed areas can be minimized and land acquisition costs made lower. With the location of industrial areas, airports, etc., known in advance, housing development can be located so as to be compatible with this development.

Finally, all development can be kept out of some areas--if that is desirable for the purpose of maximizing agricultural production, preserving scenic values and so on. The appropriation of the potential benefits from land use planning are keyed to an understanding of the capacities of the land and related resource base as a basis for determining appropriate types and levels of uses.

Summary of Control Measures Available to Political Units--

A wide variety of political institutions are available within the United States to implement the above carrying capacity controls described for the three social growth sectors. These are listed in Table 7 with an indication as to whether or not the particular political unit can effectively implement the control. In the political institutions structured by the United States Constitution in setting up a federal system, powers are largely shared by the two primary levels--state and national. Many powers are exercised by both levels, but some are reserved to the states, e.g., the police powers, and some are delegated exclusively to the national government. An example of this appears in Table 7 as indicated under population (migration) control. The power over interstate commerce was delegated exclusively to the national government by the constitution. Consequently, this important mechanism of control over migration is not available to the states or their subdivisions. Local governments (counties, townships, and municipalities) are creations of the states and share such powers as they are given to them by the states.

The most pervasive control mechanism in the areas discussed appears to be that of economic development. As all of these political structures can either choose to spend or not to spend funds for public facilities, they have some control over economic development and thereby affecting the growth of a given area. It should be noted that the definition of

Table 7. CONTROL MECHANISM AVAILABLE TO POLITICAL INSTITUTIONS

Political Institutions	Control Mechanism Available		
	Population	Economic Development	Land Use Planning
Federal Government	X	X	X
Federal Agency with regional impact or mission		X	X
Federal Corporation		X	?
Interstate Compact[a]		X	X
State Government		X	X
Interstate Compact[a]		X	X
State Corporation		X	?
Multi-County District		X	X
County		X	X
County Corporation		X	?
Special District		X	X
Township		X	X
Municipality		X	X
Municipal Corporations		X	?
Municipal District		X	X

[a] The interstate compact being created by both the State and Federal levels, working together, appears under both categories here.

public facilities can be quite broad. A political unit can build a factory to produce a public good, develop energy sources to run the factory, and then sell all of this as surplus property to a private concern at a fraction of its replacement value if it becomes public policy to do so.

Public policy, in a democracy, is set by elected officials. Consequently, the decision as to whether to intervene in the "natural system" is political. What should be done by wise men and what can be done by prudent office holders who wish to remain in office do not always present the same outcome. The decision to tax, spend, borrow or to print money, as part of a regional economic policy, is laced with the politics of partisanship, ideology, and selfish interest. One way to alleviate some of the trauma associated with the politics of decision making is to take the decision out of the political arena. Routine decisions are handled by a reasonably nonpartisan career bureaucracy. Another method is to organize a government corporation for a specific purpose. These corporations, similar to those of the private sector, are simply totally owned entities of a government. Successful examples of these include the Tennessee Valley Authority on the federal level; and state or municipal housing corporation, turnpike or bridge authorities on the nonfederal level. These political entities operate quite independent of the political units of government, because they do not have to request funds for their operation. They sell their services or produce goods that generate operating revenue, but do not possess the taxing power. They appear to be potent forces for economic development and growth as has been shown by the successful example of TVA. Their success in using land use planning, however, is not clear at the present time.

The list of available and diverse political units in Table 7 suggests a number of possibilities for implementing a strategy for controls related to the carrying capacity concept. All units have power available to influence economic development. This variable, in return, can affect population levels and land use planning activities.

If the region of concern for carrying capacity is geographically small, one of the smaller units of government might be used. If there appears to be some structural or political reason why this is not possible, the next larger unit (geographically) could be utilized. Political boundaries should not be a concern in implementing control mechanisms. Other political structures should be able to substitute if larger areas are needed.

CARRYING CAPACITY: TWO EXAMPLES OF REGIONAL PLANNING RESPONSE

In the face of the kinds of problems previously noted, a few regional planning groups have responded with studies of optimum growth and regional carrying capacity. As additional background to placing carrying capacity within the regional planning process, it is interesting to note the direction and experience of these studies.

Optimum Growth: Metropolitan Washington, D.C.

"Optimum growth: Consequences for the year 2000 in metropolitan Washington" acknowledges that there has been a breakdown of the previously held attitude regarding growth and development of communities, but that the growth ethic has not been pervasively replaced by any alternative. The report notes that planning and decision-making systems are now expected to actively promote environmental quality as a goal to be achieved rather than simply seeking to mitigate adverse environmental effects of development. This change in community attitude has brought into question the extensive use of "demand projection" by comprehensive planning approaches. Better methods are therefore needed in constructing and operationalizing regional planning systems. The concept proposed is the use of "optimum growth" and "balanced communities" as a focal point in the planning process to examine trade offs. Trying to define these terms from the standpoint of real-world, community-held values becomes complex and "quantitatively elusive." However, they do introduce a set of useful trade offs to be examined. The following are listed: 1) Diversity versus homogeneity, 2) change versus stability, and 3) community self-sufficiency versus economic basis for specialized services and institutions.

Recognizing the importance of techniques or strategies for implementing optimum growth plans, the report notes that policy level subscription to the concept of optimum growth is insufficient to implement it. Hence, planners need to focus on controlling the "drivers" of population and economic growth, and the impacts of growth. In most cases, current strategies for controlling growth are aimed at controlling the impacts of growth rather than the driving forces behind growth.

A planning and decision process useful for the implementation of a regional plan is sketched which recommends a communication format to overcome the limitations and frustrations imposed upon elected officials by differing perspectives of discussion and limited available time. The communications format emphasizes problem definition, structuring of the discussions of alternative solutions, identification of constraints, resolution of conflicts, and assignment of responsibility for action plans. These activities are carried out by representatives of the various governments in the region. Recognition of constraints and budget capacities plays an important role in the communications format. The three major constraints (or budgets) faced by planners are: 1) Natural resources budgets, or limitations imposed by the natural environment in terms of the holding capacity or carrying capacity in relation to such things as air or water quality standards; 2) physical budgets, a need for significant feedback between carrying capacity and the required public and private expenditures in applying the discussion format; and 3) community response budget, or the non-monetary concerns such as overcrowding, clean air and water, the desire to preserve community character, etc., which are perceived by members of the community.

A number of possible regional roles that would have to be filled in order to operationalize the proposed discussions and planning procedures are also outlined. Among these are (1) technical assistance for creating models of budget capacity, using budgets to determine when jurisdictions are approaching their carrying capacities and improving communications, (2) a forum for setting agendas for communication and developing roles for responsible parties, (3) regional spokesmen to occupy roles of advocacy of optimum growth control targets, (4) regional resource managers to identify the most efficient locations for growth, based on principles of resource linkage and regional specialization, and (5) control structures to link planning and implementation.

The work stress that "optimum growth" and "balanced communities" require considerable definition, but are useful terms for stimulating interrogative thinking about planning alternatives. Also, since our urban areas are very complex, the concept of optimum growth is best derived from a process and should not be stated merely as a goal. Further emphasized is the fact that control of variables that multiply downstream consequences (i.e., the drivers of economic and population growth) is preferable to controlling variables which are simply related to the impacts of growth. Regional coordination in terms of regional resource managers and regional spokesmen is required for the successful use of the optimum growth concept in regional management.

Ecology and the Economy: The Pacific Northwest

The Pacific Northwest River Basin Commission Urban and Rural Related Lands Committee has recently undertaken a study attempting to determine the extent to which a high-quality environment can be maintained in the face of population and economic growth in the Pacific Northwest. The study adopts a carrying capacity or sustained yield approach to assess the capabilities of the resources of the area to indefinitely sustain various levels of population, economic activity, and degrees of protection of natural and intangible values.

The carrying capacity approach outlined in the study was developed by using available data and best judgments to (1) describe an optimum environment for the average individual in terms of available goods, services, and intangibles, and (2) identify alternative long-range goals for the Pacific Northwest in terms of population levels, economic activity, and degree of protection of less tangible values, and (3) compare various combinations of the elements of (2) with the requirements for the "optimum" quality of life defined under (1). The description of an optimum environment or an optimum "quality of life" was obtained basically through an examination of Maslow's (1954) concept of a five-level hierarchy of human values. In brief, Maslow contends that human experience is needs-organized and that human needs are arranged in a hierarchy such that when lower level needs have been satisfied, higher level needs emerge and come into play. Maslow argues that the human being can live a quality life only when each level of human needs has been properly satisfied. The five levels of human needs identified by Maslow in the order that they emerge are (1) physiological needs such as food, shelter, clothing, sleep, etc., (2) security needs such as protection from physical harm and the assurance of a continuing income and employment, (3) social needs such as acceptance by other people, (4) ego needs such as the achievement of independence, self-esteem, recognition, etc., and (5) self-fulfillment needs such as achieving a sense of accomplishment and capability, and acceptance of new challenges.

The attainment of an optimum quality of life, i.e., the fulfillment of each level of human needs in the proper order, requires a substantial level of production of goods and services. When the mean per capita income exceeds the amount necessary to satisfy the most basic needs, the other higher level needs (which are generally more intangible) then become important. The point is that in order to achieve an optimum environment, every individual must have some minimum income.

The study defines the relationship between population and industry through use of the concept of "servant machine." The concept is applied to estimate amounts of use and consumption of resources and potential pollution and other environmental impacts caused by population and by industrial and other economic activity. On the average, one individual can produce $250 per year in goods and services. This figure divided into the per capita GNP of the average citizen of the United States ($3,490 in 1967 dollars) indicated that each individual has the use of 13 "servant machines." The assumption is that each machine would have an impact on the environment equal to that of its owner.

The capacity of a region to sustain population in industry is determined in a three-step process. First, optimum per capita income levels are calculated as a function of the description of the optimum quality of life decided upon. Second, annual capacity for indefinitely sustained productivity is projected for each of seven categories of industrial activity (commercial forest land, agricultural land, commercial fishery, recreation and tourism, location-based industry, and mining and minerals) and a total potential GRP is calculated from these estimates. Finally, the carrying capacity of the region is calculated by dividing the total potential GRP by the per capita share of GRP dictated by the optimum per capita income as defined under step one. Calculated in this way, carrying capacity has units of numbers of people, and assumes 100 percent recycling and pollution control. Lower levels of recycling and pollution control require that GRP be lower, thus lowering the carrying capacity for a given optimum per capita income.

SUMMARY

This chapter has discussed ways of incorporating carrying capacity considerations in a planning process that involves analyzing and evaluating alternative ways of constructively dealing with critical areas of change and development. In the briefest terms, a carrying capacity-based planning process involves examining how driving forces (events and decisions that occasion significant change) will affect the capacity of the resource base (water supply, labor, capital, raw materials, etc.) to support production activities; the capacity of these production activities to supply essential goods and services; the capacity of infrastructure resources (waterways, roads, transmission lines, sewerage, etc.) to distribute materials and goods and services without paralyzing congestion; and the capacity of the environmental media (air, water, land) to assimilate the wastes generated from production and consumption. The information conveyed by carrying capacities indices--measurements that indicate how near actual capacities are to limits or bounds--need to be carefully considered by regional planners and given due weight in the evaluation of programs and policies designed for the wise management of change.

SECTION IX

REFERENCES

REFERENCES CITED

Alonso, W. J. 1971. The economics of urban size. Papers of the Regional Science Association, European Congress 26:67-84.

Bahr, T. G., R. A. Cole, and H. K. Stevens. 1972. Recycling and ecosystem response to water manipulation. U.S. National Water Commission, Arlington, Virginia. 124 pp.

Baumol, W. J. 1967. Macroeconomics of unbalanced growth. American Economic Review 57:415-426.

Berry, B. J. L. 1966. Reflections on the functional economic areas. In Research and Education for Regional and Area Development, pp. 56-64. Ames, Iowa, Center for Agricultural and Economic Development, Iowa State University.

Bishop, A. B. 1973. Systems analysis. In Environmental Design and Public Projects. D. W. Hendricks, E. C. Vlachos, L. S. Tucker, and J. C. Kellogg (eds.). NSF-RANN Project GI-29837, Colorado State University, Ft. Collins, Colo.

Boulding, K. E. 1973. The economics of ecology. Proc. National Conference on Managing the Environment, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

Bower, B. T. 1971. Residuals and environmental management. J. Am. Inst. of Planners 37(4):218-220.

Bower, B. T., and D. J. Basta. 1973. Residuals--environmental quality management: Applying the concept. Center for Metropolitan Planning and Research, Johns Hopkins University, Baltimore, Md.

Bowles, G. K., et al. 1969. Net migration of the population. Economic Research Service, U.S. Dept. of Agriculture, Washington, D.C.

Cooper, W. E., and R. D. Vlasin. (no date). Ecological concepts and applications to planning. Unpublished manuscript.

Corning, P. A. 1971. Can we develop an index for quality of life? AAAS Annual Meeting.

Craven, C. W., Jr., F. P. Baxter, C. R. Meyers, Jr., R. J. Olsen, C. R. Schuller, and A. H. Voellzer. 1973. Regional environmental systems analysis. ORNL-NSF Environmental Program, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Dee, N., J. K. Baker, N. L. Drobny, K. M. Duke, and D. C. Fahringer. 1972. Environmental evaluation system for water resources planning.

Deitchman, S. J. 1972. Modeling comprehensive pollution control. Presented at ORSA National Meeting, New Orleans, Louisiana.

Euclid vs. Ambler Reality Company, 272 United States 365.

Fox, K. A. 1969. Operations research and complex social systems. In Economic Analysis and Operations Research: Optimization Techniques in Quantitative Economic Models. J. I. Sengupta and K. A. Fox (eds.). North-Holland Publishing Company, Amsterdam.

Friedmann, John. 1966. Focus on public policy. In Research and Education for Regional and Area Development, pp. 215-233. Ames, Iowa, Center for Agricultural and Economic Development, Iowa State University.

Gallaway, L. E. 1960. Geographic labor mobility in the United States, 1957 to 1960. Social Security Administration, Research Report No. 28, Washington, D. C.

Goel, N. S., S. C. Maitra, and E. W. Montroll. 1971. On the Volterra and other nonlinear models of interacting populations. Review of Modern Physics 43(2).

Goldberg, M. A., C. S. Holling, and R. F. Kelley. 1971. Vancouver regional simulation study. Proc. IGU Symposium in Urban Geography. Gleerup Publishers, Lund, Sweden.

Hardin, Garret. 1963. The cybernetics of competition: A biologists view of society. Perspectives in Biology and Medicine 7:58-84.

Herzog, H. W., Jr., and R. G. Ridker. 1972. The model. In Population, Resources, and the Environment. R. G. Ridker (ed.). U.S. Commission on Population Growth and the American Future Report Vol. III, Washington, D.C., Government Printing Office.

Hiibner, C. W. 1973. Where did all the people go. Utah Science 34(4):121-123.

Holling, C. S. 1969. Stability in ecological and social systems. Brookhaven Symposia in Biology 22:128-141.

Holling, C. S., and M. A. Goldberg. 1971. Ecology and planning. J. Am. Inst. Planners 37(4):221-230.

Holling, C. S., and G. Orlans. 1971. Toward an urban ecology. Bull. Ecological Soc. of Am. 52(2):2-6.

House. P. W. 1973. The concept of a human-oriented carrying capacity. Presented at the Colorado River Basin Environmental Management Conference, Oct. 15, 1973, Salt Lake City, Utah.

Isard, W. 1972. Ecologic-economic analysis for regional development. The Free Press, New York.

Kane, J. 1972. A primer for a new cross-impact language--KSIM. Technological Forecasting and Social Change, 4.

Koenig, H. E., and R. L. Tummala. 1972. Principles of ecosystem design and management. IEEE Transactions on Systems, Man, and Cybernetics 2(4):449-459.

Land, K. C. 1971. Some exhaustible poisson process models of divorce by marriage cohort. J. Math. Soc. 1:213-232.

Lee, E. S., et al. 1971. An introduction to urban decentralization research. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Lewis, C. W. 1972. A critical examination of the export-base theory of urban-regional growth. Annals of Regional Science, Dec. 1972. pp. 15-25.

Lewis, C. W. 1973. Growth and welfare: The effect of the spatial dimension. Unpublished manuscript, Dept. of Economics, Utah State University, Logan.

Lotka, A. J. 1925. Elements of physical biology. Williams and Wilkins, Baltimore, Md. 460 p.

Maslow, A. 1954. Motivation and personality. Harper and Row, New York.

Myers, C. W. 1973. The Arizona trade-off model. Arizona Business, March.

Perloff, H. S. 1968. A framework for dealing with the urban environment. In The Quality of the Urban Environment. H. S. Perloff (ed.). Resources for the Future, Johns Hopkins Press, Baltimore, Md. pp. 3-25.

Russell, C. S., and W. O. Spoffard, Jr. 1972. A quantitative framework for residuals management. In Environmental Quality Analysis. A. V. Kneese and B. T. Bower (eds.). Decisions. The Johns Hopkins Press, Baltimore, Md.

Technical Committee of the Thirteen Western States Water Resources Research Institute. 1971. Development of techniques for estimating the potential of water resources development in achieving national and regional social goals. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Volterra, Vito. 1926. Variation and fluctuation of numbers of individuals in animal species living together. In Animal Ecology. R. N. Chapman (ed.). McGraw Hill, New York. pp. 409-448.

Watt, K. E. F., and J. L. Wilson. 1973. Regional modeling studies by the environmental systems group. Paper presented at Conference on Regional Environmental Management, San Diego, California.

Williams, E. R., and P. W. House. 1973. Managing the environment: A case for quality growth. Unpublished manuscript, Environmental Studies Division, U.S. Environmental Protection Agency, Washington, D.C.

OTHER REFERENCES

Alldredge, R. B. Some capacity theories for Federal recreation areas. U.S. National Park Serv. unpub. rept., 7 p.

Amos, F. J. C., and G. Cowley. Development of the planning process. Royal Town Planning Institute Journal 57 (July):304-308. 1971.

Andersen, J. C. Economic, technological, and policy considerations of stock resources. American Journal of Agricultural Economics 50(5):1630-1634. December 1968.

Andersen, J. C. Some unresolved issues in measuring regional growth. Proceedings of the Western Agricultural Economics Association, pp. 246-254. 1969.

Ayres, R. U., and A. V. Kneese. Pollution and environmental quality. In The Quality of the Urban Environment. H. S. Perloff (ed.). Resources for the Future, Johns Hopkins Press, Baltimore, Md. 1969.

Barnett, Harold J., and Chandler Morse. Scarcity and growth: The economics of natural resource availability. Johns Hopkins Press, Baltimore, Md. 1963.

Berry, Brian J. L. Commuting patterns: Labor market participation and regional potential. In Growth and Change: A Journal of Regional Development 1:3-10. October 1970.

Bishop, A. B., A. B. Crawford, H. H. Fullerton, and R. E. Toth. The concept of carrying capacity. Report for the National Conference on Managing the Environment, EPA, Washington, D.C. Office of Research and Development. 1973.

Boventer, Edwin von. Spatial organization theory as a basis for regional planning. Journal of the American Institute of Planners 30:90-100. 1964.

Bowden, E. V. The theory and the practice of regional development economics. Land Economics 47(2):113-121. 1971.

Boyce, D. E. Toward a framework for defining and applying urban indicators in plan-making. Urban Affairs Quarterly, p. 145-171. December 1970.

Brandborg, Stewart. On the carrying capacity of wilderness. Living Wilderness 32:29-33. 1963.

Breton, A. Towards an economic theory of pollution control and abatement. Pollution and Our Environment Conference, Background Papers. Montreal Canadian Council of Resource Ministers, Paper D 281. 1967.

Caldwell, Lynton Keith. Biopolitics: Science, ethics and public policy. Yale Review 54:1-16. 1964.

Caldwell, Lynton Keith. Problems of applied ecology perceptions, institutions, methods and operational tools. Bioscience 16:524-527. 1966.

Caldwell, Lynton K. The ecosystem as a criterion for public land policy. Natural Resources Journal. April 1970.

Carpenter, R. A. Information for decisions in environmental policy. Science. June 12, 1970.

Chadwick, George F. A systems view of planning. Town Planning Institute Journal 52:184-186. 1966.

Chen, Kan. A macrosystem analysis of the human environment. J. Environmental System. June 1971.

Ciriacy-Wantrup, Siegfried von, and J. J. Parsons (eds.). Natural resources: Quality and quantity. University of California Press, Berkeley. 1967.

Cloud, Preston. Realities of resource distribution. Texas Quarterly (Summer). 1968.

Commoner, Barry. Balance of nature. In Providing Quality Environment in Our Communities, U.S. Department of Agriculture, Graduate School Press, Washington, D.C. 1968.

Council on Environmental Quality. Third annual report. U.S. Government Printing Office, Washington, D.C. 1972.

Cox, P. T., C. W. Grover, and G. Siskin. Effect of water resource investment on economic growth. Water Resources Research 7(1):32-38. 1971.

Crocker, T. C., and A. J. Rogers, III. Environmental economics. Dryden Press, Hindsdale, Illinois. 1971.

Czamanski, S. Some empirical evidence of the strengths of linkages between group of related industries in urban-regional complexes. RSAP 27:137. 1971.

d'Arge, R. C. Economic growth and the natural environment. In Environmental Quality Analysis, A. V. Kneese and B. T. Bower (eds.). Resources for the Future, Johns Hopkins Press, Baltimore, Md. 1972.

Ehrlich, Paul R., and Anne H. Ehrlich. Population, resources, environment: Issues in human ecology. W. H. Freeman and Company, San Francisco, California. 1972.

Fisher, Anthony C., and John V. Krutilla. Determination of optimal capacity of resource-based recreation facilities. Natural Resources Journal 12:417-443. July 1, 1972.

Forrester, Jay W. Industrial dynamics. John Wiley & Sons, Inc., New York, N.Y. 1961.

Fox, Karl A., and R. Krishna Kumar. Delineating functional economic areas. In Research and Education for Regional and Area Development. pp. 13-55. Ames, Iowa, Center for Agricultural and Economic Development, Iowa State University. 1966.

Freeman, D. M. Politics of planning and the problem of public confidence: A sociology of conflict approach. Dept. of Sociology, Colorado State University, Fort Collins, Colorado. 1972.

Friedmann, John. Future of comprehensive urban planning: A critique. Public Administration Review 31:315-326. May 1971.

Friedmann, John, and William Alonso (eds.). Regional development and planning. Cambridge, Mass. 1964.

Garrison, W. L. Toward simulation models of urban growth and development. Proceedings of the IGU Symposium in Urban Geography, Lund, 1960, C. W. K. Gleerup Publishers, Lund, Sweden. 1962.

Goldberg, M. A., C. S. Holling, and R. F. Kelley. Vancouver regional simulation study 1970-71. Resource Science Center, the University of British Columbia, Vancouver 8, Canada. 1971.

Gordon, R. L. Conservation and the theory of exhaustible resources. Canadian Journal of Economics and Political Science 32:319-326. 1966.

Grad, R. P., G. W. Rathjens, and A. J. Rosenthal. Environmental control: Priorities, politics and the law. Columbia University Press, New York. 1971.

Green, James L. Economic ecology: Baselines for urban development. University of Georgia Press, Athens, Ga. 1969. 167 p.

Green, Leon, Jr. Energy needs vs. environmental pollution: A reconciliation? Science 156:1448-1450. 1967.

Hall, Peter Geoffrey. The theory and practice of regional planning. Pemberton, London. 1970.

Hamilton, Henry R. Systems, simulation for regional analysis: An application to river-basin planning. MIT Press, Cambridge, Mass. 1968.

Healey, P. Planning and scarce resources--and other diversions. Royal Town Planning Institute Journal 57:410-411. November 1971.

Hemmens, G. C. The structure of urban activity linkage. Center for Urban and Regional Studies, University of North Carolina, Chapel Hill, North Carolina. 1966.

Herfindahl, Orris C., and Allen V. Kneese. The quality of the environment: An economic approach to some problems in using land, water and air. Published for Resources for the Future by the Johns Hopkins Press, Baltimore, Md. (333 H27). 1965.

Hills, G. A. The ecological basis for land-use planning. Ontario Department of Lands and Forests Research Rept. No. 46. 1961. 192 p.

Hirsch, W. Z., S. Sonenblum, and J. St. Dennis. Application of input-output techniques to quality of urban life indicators. Institute of Government and Public Affairs, University of California, Los Angeles, California. 1970.

Holling, C. S., and S. Ewing. Blind man's bluff: Exploring the response space generated by realistic ecological simulation models. Proc. Int. Symp. Statist. Ecol., Yale University Press 2:207-229. 1971.

Hufschmidt, M. Environmental planning. American Behavioral Scientist pp. 6-8. 1968.

Hyres, R. U. A materials-process-product model. In Environmental Quality Analysis, H. V. Kneese and B. T. Bower (eds.). Resources for the Future, Johns Hopkins Press, Baltimore, Md. 1972.

Isard, Walter. Location and the space economy. The Massachusetts Institute of Technology Press, Cambridge, Mass. 1956.

Isard, Walter. Methods of regional analysis. The Massachusetts Institute of Technology Press, Cambridge, Mass. 1960.

Isard, Walter. The linkage of socio-economic and ecological systems. The Regional Science Association Papers 21:79. 1968.

Isard, Walter, et al. General theory: Social, political, economic, and regional, is the particular reference to decision-making analysis. Massachusetts Institute of Technology Press, Cambridge, Mass. 1969.

Jarrett, Henry (ed.). Environmental quality in a growing economy. The Johns Hopkins Press, Baltimore, Maryland. 1966.

Jones, M. V., and M. J. Flax. The quality of life in metropolitan Washington (D.C.). The Urban Institute, Washington, D.C. 1970.

Kates, R. Comprehensive environmental planning. In Regional Planning: Challenge and Prospects, M. Hufschmidt (ed.). Praeger, New York. 1969.

Kneese, Allen V., and Blair T. Bower (eds.). Environmental quality analysis, theory and method in the social sciences. Published for Resources for the Future, Inc. by The Johns Hopkins Press, Baltimore, Md., 1972. 408 p.

Lansberg, H. H., L. L. Fischman, and J. L. Fisher. Resources in America's future. Johns Hopkins Press, Baltimore, Md. 1963.

Leopold, Luna B. Quantitative comparison of some aesthetic factors among rivers. U.S. Geological Survey Circular 620, Washington, D.C. 1969. iii + 16.

Leven, C. L., J. B. Legler, and P. Shapiro. An analytical framework for regional development policy. Massachusetts Institute of Technology Press, Cambridge, Mass. 1970.

Lewis, W. C. Public investment impact and regional economic growth. Water Resources Research 9:851. 1973.

Lewis, W. Cris, Jay C. Andersen, Herbert H. Fullerton, and B. Delworth Gardner. Regional Economic Development--the Role of Water, No. PB-206-372, National Technical Information Service. 1972.

Lime, D. W., and G. H. Stankey. Carrying capacity: Maintaining outdoor recreation quality: Consortium for environmental forestry studies. Proc. of Symposium, pp. 174-184. 1971.

Masser, I. Analytical models for urban and regional planning. Halsted Press Div. J. Wiley, New York. 1972.

Michael, J. M. Systematic planning for environmental improvement. American Journal of Public Health 6067:1205-1212. 1970.

National Goals Research Staff. Toward balanced growth: Quantity with quality. U.S. Government Printing Office. July 1970.

National Planning Association. Methods of setting goals for policy purposes. 1972.

Nautiyal, J. C., and P. H. Pearse. Optimizing the conversion to sustained yield--a programming solution. Forest Science 13:131-139. 1967.

Norsworthy, J. R., and A. Teller. The use of input-output analysis to design a study of the regional impact of air pollution control. Paper presented at the 62nd Annual Meeting, Air Pollution Control Association, New York. June 22-26, 1969.

North, D. C. Location theory and regional economic growth. Journal of Political Economy 63:243-258. 1955.

Odum, Eugene P. Fundamentals of ecology. 3rd edition. Saunders, Philadelphia. 1971.

Perloff, Harvey S. (ed.). The quality of the urban environment. Essays on "New Resources" in an Urban Age. Published by Resources for the Future, Inc., distributed by the Johns Hopkins Press, Baltimore, Md. 1969. 332 p.

Peterson, E. K. Ecology and the economy--a concept for balancing long range goals--the Pacific Northwest example. Pacific Northwest River Basins Commission. A discussion draft prepared by the Urban and Rural Lands Committee. 1972. 163 p.

Putman, S. H. The effect of changing transport facilities on regional economic development: A case study of causal analysis. RSAP 27:151. 1971.

Rand Corporation. Transportation for future urban communities. A study prospective Rm-2824 FF Rand Corporation, Santa Monica, California. 1961.

Sengupta, J. I., and K. A. Fox (eds.). Economic analysis and operations research: Optimization techniques in quantitative economic models. North-Holland Publishing Company, Amsterdam. 1969.

Shepard, Paul, and Daniel McKinley. The subversive science: Essays toward an ecology of man. Houghton Mifflin, Boston, Mass. 1969.

Sonenblum, S. The uses and development of regional projections. Report: Conference on Urban Economics, Washington, D.C. 1967.

Sorensen, J. C. A framework for identification and control of resources degradation and conflict in the multiple use of the coastal zone. M.S. Thesis, Dept. of Landscape Architecture, University of California Press, Berkeley. 1971. (In press)

Spivey, W. A., and W. E. Wecker. Regional economic forecasting concepts and methodology. RSAP 28:257. 1972.

Stanford Research Institute. Toward master social indicators. 1971.

Stearns, Forest. Urban ecology today. (AAAS Symposium) Science 170:1006-1007. November 1970.

Steinitz, Carl. Landscape resources analysis: The state of the art. Landscape Architecture 60(2):101-105. 1970.

Steinitz, Carl. A system analysis model of urbanization and change: An experiment in interdisciplinary education. Massachusetts Institute of Technology Press, Cambridge, Mass. 1970.

Teller, A. The use of linear programming to estimate the cost of some alternative air pollution abatement policies. Proceedings of IBM Scientific Computing Symposium on Water and Air Resource Management. Yorktown Heights, New York. October 23-25, 1967.

U.S. Dept. of Health, Education, and Welfare. Toward a social report. 1969.

Van Dyne, G. M. (ed.). The ecosystem concept in natural resource management. Academic Press, New York. 1969.

Watt, Kenneth E. F. Computers and the evaluation of resource management strategies. American Scientist 52:408-418. 1964.

Wendt, P. F. Land use simulation models: New horizons in comprehensive planning for urban growth and change. Reprint: Town Planning Review 41(2):161-167. 1970.

White, L. The historical roots of our ecological crisis. Science 155:1203-1207. 1967.

Zimmerman, J. F. Political boundaries and air pollution control. Journal of Urban Law 46:173. 1968.